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Serial No. 10/802,242
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PATENT & TRADEMARK OFFICE

PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant:	Markhovsky et al.
Serial No.:	10/806,242
Conf. No.:	2493
Filed:	Feb. 24, 2004
For:	METHOD AND SYSTEM FOR FINDING
Art Unit:	2681
Examiner:	To be assigned

I hereby certify that this paper is being deposited with the United States Postal Service as EXPRESS MAIL EJ-529230556-US in an envelope addressed to: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450, on this date.

October 5, 2004
Date

Registration No.34,749
Attorney for Applicant(s)

PETITION TO CORRECT PCT PRIORITY DATE

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

In response to the above-identified notice and formalities letter mailed August 6, 2004, Applicant petitions to correct the PCT Application Priority Date.

1. Applicant submits the Filing Receipt Confirmation No. 2493.
2. Applicant respectfully submits Return Reply Postcard of the filing of the Utility Application (10/786,144) on Feb. 24, 2004, which converted the Provisional Application (60/449,702) that was filed on Feb. 24, 2003.
3. Applicant respectfully submits Return Reply Postcard of the filing of the PCT Application (10/806,242) on Feb. 24, 2004, which converted the Provisional

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Application (60/449,702) that was filed on Feb. 24, 2003.

4. A petition fee of $130 (#285) is supplied herewith.
5. Applicant respectfully submits a copy of the priority document - Provisional Application 60/449,702 is supplied herewith.

REMARKS

Applicant submits this petition to correct the Domestic Priority data as cited in the Filing Receipt. A further purpose is to determine the PCT time limits at this early stage.

Applicant's first attorney requested a PCT on Feb. 24, 2004 and submitted the Provisional Application (60/449,702) but failed to file the specification of the Utility Application (10/786,144). The specification of the Utility Application (10/786,144) was filed in the U.S. Patent and Trademark Office on Feb. 24, 2004 by Applicant's undersigned (second) attorney. *See* Postcard #1. In response to the U.S. Patent and Trademark Office's request for the payment of the PCT fee by March 24, 2004 sent to Applicant's first attorney, which was forwarded to Applicant's undersigned attorney, Applicant filed the specification of the Utility Application (10/786,144) claiming priority to Provisional Application (60/449,702) and required PCT filing fee. *See* Postcard #2 and Filing Receipt. As a preventative measure, Applicant's attorney filed a PCT continuation document referencing the Applicant filed Provisional Application (60/449,702), the Utility Application (10/786,144), and PCT/US04/00542 to put all three dates initially in the filing so as to obtain the correct priority date. MPEP 1836.

In responding the Notice of Missing parts, Applicant petitions to have the PCT priority date be Feb. 24, 2003. All documents were received in the Patent Office on the same date and applicant at that time was attempting to point to the proper priority date. Applicant made such filings without deceptive intent. Such filings are due obvious errors that are allowed to be rectified. MPEP 1836.

For the foregoing reasons, Applicant believes that the priority date of Feb. 24, 2003 should be established. Applicant seeks to rectify such obvious errors in the documents at this time and put the PCT application in condition for examination and publication which is respectfully requested. Applicants' attorney should be contacted for any additional information. Applicant requests a favorable decision on its petition.

Respectfully submitted,

INTELLECTUAL PROPERTY ADVISORS, LLC

By Damian Wasserbauer

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October 5, 2004

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Patent Return Receipt Postcard

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RUSS MARKHOVSKY ET AL. — UTILITY PATENT FOR
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APPL NO.	FILING OR 371 (c) DATE	ART UNIT	FIL FEE REC'D	ATTY.DOCKET NO	DRAWINGS	TOT CLMS	IND CLMS
10/806,242	03/24/2004	3662	1810	RM-1001	30	121	15

CONFIRMATION NO. 2493

DAMIAN G. WASSERBAUER, ESQ.
Intellectual Property Advisors LLC
PO Box 156
Canton, CT 06019

FILING RECEIPT

OC000000013464770

Date Mailed: 08/06/2004

Receipt is acknowledged of this regular Patent Application. It will be considered in its order and you will be notified as to the results of the examination. Be sure to provide the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION when inquiring about this application. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please write to the Office of Initial Patent Examination's Filing Receipt Corrections, facsimile number 703-746-9195. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections (if appropriate).**

Applicant(s)

Russ Markhovsky, Edgewater, MD;

Domestic Priority data as claimed by applicant

This application is a CON of PCT/US04/00542 01/12/2004 *
which claims benefit of 60/449,702 02/24/2003
(*)Data provided by applicant is not consistent with PTO records.

Foreign Applications

If Required, Foreign Filing License Granted: 07/26/2004

Projected Publication Date: To Be Determined - pending completion of Missing Parts

Non-Publication Request: No

Early Publication Request: No

**** SMALL ENTITY ****

Title

Method and system for finding

Preliminary Class
342

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Title 35, United States Code, Section 184
Title 37, Code of Federal Regulations, 5.11 & 5.15

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APPLICATION

Of

RUSS MARKHOVSKY
For

UNITED STATES LETTERS PATENT

On

METHOD AND SYSTEM FOR DETERMINING THE LOCATION OF STATIONARY OR MOBILE SUBJECTS

Docket No. 7328

I hereby certify that this paper is being deposited with the United States Postal Service as Express Mail No. EV208228046US in an envelope addressed to: Commissioner for Patents, Washington, DC 20231, on February 24, 2003.

Reinhart Boerner Van Deuren, s.c.

Dated: Februar 24, 2003

By:______________________
Leonard J. Kalinowski

METHOD AND SYSTEM FOR DETERMINING THE LOCATION OF STATIONARY OR MOBILE SUBJECTS

BACKGROUND OF THE INVENTION

[0001] Field of the Invention – The present invention relates generally to locator systems, and more particularly, to a tracking and locating system for determining the location of stationary or mobile subjects.

[0002] Most systems for locating a subject employ the use of direction locating antennas to determine the position of the subject. However, such locating systems are characterized by shortcomings associated with the size of the antenna at the bandwidth that is optimal for the application. Direction locating antennas experience significant degradation of directional capabilities in close range conditions wherein the separation between a search unit and a target is about several hundred feet or less.

[0003] It is well known that there is a correlation between antenna size and RF wavelength. A larger antenna is needed for a longer RF wavelength. The need for small antenna size forces the selection of relatively high frequency bands of 900MHz and higher where there is a lot of interference in the form of reflections and where there is considerable signal degradation as the signal passes over small objects/obstacles. In short, relatively high frequency bands are not suited for searches where the separation between the search unit and the target is greater than a hundred feet.

[0004] Moreover, the use of directional antennas precludes coordinated searches wherein several search units are homing in on a target or are tracking multiple targets. The use of directional antennas also precludes monitoring a plurality of subjects at the same time because a monitoring unit employing a directional antenna cannot receive and transmit signals in multiple directions.

[0005] Because of significant directional errors that are associated with directional antennas, the operator also is required to have special skills in performing the search, i.e. locator systems employing directional antennas are not user friendly.

[0006] Known locator systems rely on distance measurement to determine the separation between a monitoring unit and a subject whose location is being monitored. Distance measurement generally is carried out either by measuring signal strength or by measuring the propagation time between sending a ranging signal and receiving a ranging signal. Examples of systems that use signal strength to determine distance to locate a subject are disclosed in United States Patent No. 5,086,290 and in United States Patent No. 5,650,769, for example.

[0007] Systems that rely on measurement of signal strength are prone to be unreliable due to noise, interference, signal strength changes, reflections, etc. as well as signal degradation as the signals pass over obstacles. Also, measurement error is a function of signal strength.

[0008] Moreover, large signal attenuation occurs within a building as opposed to outside of a building, while the distance change is small. Also, the accuracy of measurement is distance dependent and is less accurate at larger distances.

[0009] A further known system, which is disclosed in United States Patent No. 5,525,967, uses timing to determine distance. Time measurement does not rely on signal strength and is immune to the signal attenuation. Also, the distance measurement error is constant and does not distant depend.

[0010] Some of the known time measurement locator systems rely on variations of directional antennas, for example a phase array antenna. Such variations allow to reduce the antenna size. However, the price for these improvements is an extremely complex signal processing requirements which result in a lower accuracy, higher cost and power consumption. Also, these antennas are subject to operating frequency limitations (see above) and require a wide bandwidth.

[0011] Known distance measurement systems that employ time-measurement techniques require a large bandwidth in order to achieve a desired accuracy. This results in increased interference, higher circuit complexity and power consumption as well as higher cost. Wide bandwidth requirements also limit

the number of devices that can operate simultaneously. Because of wide bandwidth requirements these devices cannot operate on business bands or unlicensed bands, which prohibits these transmit/receive units from being sold "over the counter" or integrated with mass-produced popular hand-held radios.

[0012] In United States Patent Publication No. 2002/0155845, there is disclosed a position location system that uses spread spectrum technology for determining range information in a severe multi-path environment. The system uses a ranging process wherein ranging pulses at eight different frequencies are exchanged between a master radio unit and each of at least four reference radio units. The position and velocity information obtained by the ranging process enables determination of the position of the master radio's position in three dimensions.

[0013] This system uses a variation of time-measurement based techniques for distance determination. As a result, it carries all of the drawbacks mentioned above plus its operation frequencies/bands are limited.

[0014] The system does not employ a directional antenna. Instead, it uses four fixed references with known coordinates, or four mobile references that have their coordinates continuously updated via GPS or manually. This system allows simultaneous operation of many units. In this system, the usage of a directional antenna is eliminated at a price of an extreme complexity (technological and logistical), cost and power consumption. As a result, the system can be used only in a few niche markets.

SUMMARY OF THE INVENTION

[0015] The disadvantages and limitations of the background art discussed above are overcome by the present invention. With this invention, there is provided a system for determining the location of a fixed or mobile subject. The system employs one or more monitoring units and one or more monitored units that are worn or carried by a subject, such as a child, whose location it is desired to monitor.

[0016] One aspect of the invention is measuring the propagation time of the RF signals rather than measuring the distance between a transponder of a monitoring unit and a transponder of a monitored unit carried or worn by a child being monitored by the RF signal strength.

[0017] Another aspect of the invention is the use of a "finder" algorithm, rather than a directional antenna, to home-in on a child's position when the child moves out of a permissible range. This mode of operation also allows coordinated searches where several master units are homing in on a target or are tracking multiple targets while, at the same time, the master units are monitoring other children.

[0018] A further aspect of the invention is continuously calibrating the monitoring unit, allowing compensation for internal timing delays of electronic and electrical circuits of the monitoring and monitored units.

[0019] The invention time-measurement techniques/circuits have low complexity, deliver high accuracy at a very low bandwidth and are low in cost and power consumption, without limits of the operating frequency/band, reducing the technology complexity.

[0020] The invention “finder” algorithm is capable of operating with or without fixed/mobile references and does not require the reference coordinates be updated, thus significantly reduces the logistics complexity.

[0021] The invention “finder” algorithm is designed to improve the position determination accuracy by minimizing the so-called position ambiguity error as is described herein.

[0022] Unlike prior art systems (for example, the system disclosed in United States Patent Publication No. 2002/0155845) in one embodiment, the present invention provides for functional differences between the master and slave units at least in part for the purpose of minimizing power requirements and lowering the cost and size for the slave units. For example, in one embodiment, the slave units cannot issue commands, cannot "talk" to each other; do not have a keypad or a display, and have limited computing power.

[0023] In operation, a monitoring unit periodically transmits an RF signal for detection by monitored units. The monitoring unit receives reply RF signals transmitted to the monitoring unit by the monitored units. The monitoring unit measures the time between the RF signals to determine if the subject whose location is being monitored is within the preset range, typically 10 – 30 meters.

[0024] If the subject moves out of the preset range, the monitoring unit automatically enters a search mode, activating a "finder" algorithm executed by a processor of the monitoring unit.

[0025] In prior art locator systems that are measuring the propagation time of the RF signals, the RF signal propagation delay becomes a problem, particularly due to delays within the electronics of the monitoring and monitored units. This is due, in part, to the RF signal being propagated at the speed of light in air, but at a slower speed in the electronics. This problem is solved by the present invention which calibrating the circuits of the monitoring and monitored units. Thus, the present invention uses calibration to allow compensation for propagation delays through the electronic circuits of the monitoring and monitored units and initiates an algorithm to search, rather than employing a directional antenna to obtain direction or bearing readings.

DESCRIPTION OF THE DRAWINGS

[0026] These and other advantages of the present invention are best understood with reference to the drawings, in which:

[0027] FIG. 1 is a simplified representation of an RF mobile tracking and locating system provided by the present invention;

[0028] FIG. 2 is a block diagram of a master unit of the RF mobile tracking and locating system of FIG. 1;

[0029] FIG. 2A a simplified representation of the master unit of FIG. 2;

[0030] FIG. 3 is a block diagram of a slave unit of the RF mobile tracking and locating system of FIG. 1;

[0031] FIG. 3A a simplified representation of the slave unit of FIG. 3;

[0032] FIG. 3B illustrates the format for data packets used for communications between the master and slave units;

[0033] FIG. 3C illustrates the format for identification fields for the data packet format of FIG. 3B;

[0034] FIG. 3D illustrates the format for the data field for the data packet format of FIG. 3B;

[0035] FIG. 4 is a block diagram of a master unit and a slave unit of the tracking and locating system of FIG. 1, and illustrating the timing points through the circuits of a master unit and the slave unit during signal transmission;

[0036] FIG. 4A is a timing diagram illustrating the states sequence of the master and slave units of the tracking and locating system of FIG. 1, including a first-calibration option;

[0037] FIG. 4B is a timing diagram illustrating the states sequence of the master and slave units of the tracking and locating system of FIG. 1, including a second calibration option;

[0038] FIG. 5 is a functional block diagram of the master unit of FIG. 2;

[0039] FIG. 6 is a functional block diagram of the slave unit of FIG. 3;

[0040] FIG. 6X is a simplified representation of the allocation of frequency ranges of the modulation bandwidth to allow multiplexing of voice, ranging signals and data transmission for the RF mobile tracking and locating system of FIG. 1;

[0041] FIG. 7 is a graph showing position determination in accordance with the present invention;

[0042] FIG. 8 is a graph showing ambiguity in the position determination according to FIG. 7;

[0043] FIG. 9 is a graph showing position ambiguity as a function of distance measurement error for the position determination method of FIG. 7;

[0044] FIG. 10 is a graph showing an example of ambiguity reduction in accordance with the invention;

[0045] FIG. 11 is a graph showing another example of ambiguity reduction in accordance with the invention;

[0046] FIGS. 12 and 13 are a process flow chart illustrating an Algorithm 1 for determining location of a target;

[0047] FIG. 12A is a process flow chart illustrating an Algorithm 2 for determining location of a target;

[0048] FIG. 14 is a process flow chart illustrating an Algorithm 3 for determining location of a target;

[0049] FIG. 15 illustrates the homing process for determining location of a child in accordance with the invention using Algorithm 1, where no reference units are needed;

[0050] FIG. 16 is a diagram illustrating an example of homing using three stationary monitor reference units, providing a fixed reference for the process of FIG. 14;

[0051] FIG. 17 is a diagram similar to that of FIG. 16 and showing virtual coordinates rotated for mapping into a display grid;

[0052] FIG. 18 shows a display grid that can be displayed by a display unit of the master unit for showing results for homing using Algorithm 3 with three stationary reference units according to FIGS. 16 and 17;

[0053] FIG. 19 is a display grid that can be displayed by a display unit of the master unit for showing the results of homing using Algorithm 3 with three moving reference units;

[0054] FIG. 20 is a diagram showing use of Algorithm 2 for homing with three stationary child units, with virtual coordinates rotated;

[0055] FIG. 21 is a graph illustrating the use of Algorithm 2 for homing with three stationary child devices in accordance with the invention; and

[0056] FIG. 22 is a graph similar to that of FIG. 21 and illustrating obstacle avoidance or bypassing operation.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0057] Referring to FIG. 1, there is shown components of a tracking and locating system 20 provided by the present invention. The tracking and locating system 20 is described with reference to an application for monitoring the location of human subjects, particularly children, allowing tracking and locating the subjects. However, the tracking and monitoring can also be used for tracking and locating other animate objects such as pets and other animals. In addition, the tracking and locating system can be used in locating one or more inanimate objects such as keys, eyeglasses, wallets, purses, portable telephones or cell phones, remotes for television sets, video cassette recorders and digital versatile disc players, and generally any item which can be hand carried by a person and is prone to misplacement. This technology can be also combined with GPS technology as described herein. Moreover, in some applications, the slave unit electronics can be embedded in to an object or a document, for example a golf ball as is described below.

[0058] The tracking and locating system 20 includes one or more master units, such as master units 21, 22, 23 and one or more slave units, such as slave units 31, 32, 33 and 34. The master units are used for monitoring the location of subjects, allowing tracking and locating the subjects. The slave units are carried or worn by the subjects being monitored. Communication between the master units and the slave units is carried using RF signaling techniques.

[0059] The master and slave units can be located at any position within the communicating range of the master and slave units in the manner described herein to convey position and range related information. By way of example, the master unit 21 can be carried by a parent or guardian and the slave unit 31 can be carried or worn by a child or other person whose location is to be monitored.

[0060] The master units are preset or programmed to monitor slave units to determine whether the slave units are within a preset range, typically set to be

ten to thirty meters. For example, the range for master unit 21 is represented by the circle 25 of radius R shown in FIG. 1. The master unit 21 is located at the center of the circle 25 and the permissible range, relative to master unit 21, being the radius R of the circle. Note that the slave unit 31 is outside of the permissible range relative to master unit 21 and the slave units 32-34 are within the permissible range. However, in the example, the slave unit 31 can be within the permissible range of at least master unit 23. This range is not the receiving range, but rather represents an allowable separation between the location of a slave unit 31 relative to the master unit 21.

[0061] Each master unit can communicate with the four slave units 31-34 to determine the position of the slave units. The master units transmit ranging signals to the slave units and receive reply ranging signals from the slave units. Each master and slave unit has its own unique identification code or address such that each master and slave unit is individually addressable. Master and slave units can operate on the same frequency or, in one embodiment, different frequencies are used for transmitting from the master units to the slave units and transmitting from the slave units back to the master units. This allows full-duplex audio, video and data message transmission/communication and may provide additional benefits that will be described later.

[0062] Moreover, the tracking and locating system 20 also can provide for voice communication either bidirectionally or unidirectionally from the master units to the slave units. However, in one embodiment, the slave units do not have a speaker or microphone, but in such embodiment, the slave units can be adapted to receive a headset/microphone, for example, allowing bidirectional voice communication.

[0063] Each master unit, such as master unit 21, operates to periodically determine the distance between the master unit and each of the slave units 31-34. This is done by sending a ranging signal to the slave units. The slave units 31-34, such as slave unit 31, responsively transmit a reply ranging signal back to the master unit 21. The master unit 21 responds to the reply ranging signal

received from the slave unit 31 and measures the time elapsed between the transmission of ranging signals to and the reception of reply ranging signals from a slave unit. **[0064]** In one embodiment, a signal processor unit in the master or monitoring unit 21 keeps track of the time that the signal was sent to locate the target unit 31. With this information, together with the information about the time of incidence of the ranging signal, the processor unit is able to calculate the distance between the slave or target unit 31 and the master or monitoring unit 21. This distance is determined by taking the elapsed time, i.e., the total time that it takes for a ranging signal originated by the master unit 21 to travel from the master or monitoring unit 21 to the slave or target unit 31 and a reply ranging signal originated by the slave unit 31 to travel back to the master or monitoring unit 21 from the slave or target unit 31, less an offset amount that is indicative of internal delays of the slave or target unit 31 and the master or monitoring unit 21. For short distances, a few hundred meters or less, the propagation delays within the master and slave units becomes a problem. The RF signal is transmitted at the speed of light in air, but is transmitted slower in the electronic circuits of the master unit 21 and the slave unit 31 due to propagation delays, which are varying over temperature, supply voltage, time, etc.. The problem is solved by calibrating to determine the propagation time through the master and slave units to determine a "correction" or offset time. This correction time is subtracted from the total time in making range calculations. The offset amount is determined using a calibration/loop back procedure as will be described. Also, in order to increase the accuracy of a single measurement, the ranging signal may continuously traverse more than once between master and slave units before a measurement is made, as will be described.

[0065] The ranging signal propagation time can be measured directly (as described above) or indirectly. In another embodiment, ranging signals are successively transmitted and the tracking and locating system uses detection of phase shift between successive ranging signals. One example of such indirect

measurement is the ranging signal phase shift measurement. This phase shift is proportional to the distance traveled by the ranging signal as well as propagation delays (offset) in the electronic circuits of the master and slave units. The propagation delays in the master and slave units are determined using a calibration procedure.

[0066] The operating cycle includes measuring the delay time (i.e., "calibrating" or periodically testing the master and slave units) to determine the signal propagation time through the unit; continuously test. In one embodiment, calibration is carried out at the beginning of each transmission. However, calibration can be carried out on a periodic basis.

[0067] If when a slave unit, such as slave unit 31 in the example illustrated in FIG. 1, is moved out of the allowable range, the master unit 21 automatically enters a search or homing mode. In the search or homing mode, the master unit 21 uses an algorithm to determine the location of a slave unit that is out of the allowable range. The search mode is based on a form of triangulation that allows homing in on the slave unit 31. The invention results in higher accuracy and the "outcome" is assured.

[0068] As will be shown, the algorithm takes care of various scenarios. For example, the slave unit 31 can be stationary, or substantially stationary, in which case, the location of the slave unit 31 can be determined using a single master unit 21. The user with the master unit 21 moves in a pattern and the master unit 21 periodically checks to determine the target position relative to the user with the master unit 21 and gives instructions to the user, in order to correct the path of movement.

[0069] In addition, one or more of the master units, such as master units 22 and 23, can function as a fixed or mobile position reference for the master unit 21 in determining the location of a slave unit, such as slave unit 31, as will be described. This allows the location of the slave unit 31 to be determined relative to a master unit 21 when the subject is stationary or is moving relative to the master unit 21. In one embodiment, a plurality of master units, such as

master units 22-23, can be used as position reference units in determining the location of a slave unit, such as slave unit 31, with the position reference units being fixed or movable with respect to the master unit 21 that originated the location operation. Also, stationary slave units can be employed as a fixed reference.

[0070] In one embodiment, the time of arrival of ranging signals transmitted between a master unit, such as master unit 21 and slave units, is used to determine the distance to each slave unit with respect to a master unit, such as master unit 21. If any of the slave units is moved out of the permissible range, a search mode is entered during which a form of triangulation technique is used to determine from the range measurements provided by the master unit 21, the relative location between the master unit 21 and the slave unit that is currently out of range.

[0071] In another embodiment in which the slave unit 31 is moving relative to the master unit 21 at a relatively slow rate, a plurality of fixed position reference units, such as master units 22 and 23 or fixed slave units (not shown in FIG. 1), can be used to provide position reference points, allowing the user using a single master unit 21 to determine the location of the target associated with the slave unit 31.

[0072] In a further embodiment in which the slave unit 31 is moving fast with respect to the master unit 21, a plurality of mobile position reference units are used to define references that can be used by the master unit 21 to determine the location of the target. Preferably, the mobile position reference units are master units 22-23. In this embodiment, the master units that provide the reference signals as well as the master unit 21 that is being used to locate the target can be moving with respect to the target and with respect to one another. This mode of operation allows coordinated searches where several master units are homing in on a target or are tracking multiple targets while, at the same time, monitoring other targets such as those associated with slave units 32-34.

[0073] In one embodiment, the ranging signal includes frequency modulated RF signals transmitted in four channels, one channel for each of the slave units 31-34. In addition, with modifications that are apparent to those skilled in the art, the master and slave units can transmit in the same frequency bands using a time division multiplexing arrangement.

[0074] The foregoing general description makes specific reference to master unit 21 and slave unit 31. However, each of the other master units 22 and 23 can function in the manner described for master unit 21, and the slave units 32-34 can function in the manner of slave unit 31 in the manner described for slave unit 31. Moreover, all of the master units and all of the slave units can serve as a position reference unit, and, for example, master units 21 and 23 can serve as mobile position reference units for master unit 22, and master units 21 and 22 can serve as mobile position reference units for master unit 23.

[0075] While in the exemplary tracking and locating system 20 only four slave units are shown and discussed, in a more typical system, there are up to seven slave units and seven transmission channels are defined for monitoring the seven slave units. In applications where it is necessary to monitor more than seven slave units, the number of transmission channels available in the exemplary could be exhausted. In such application, the tracking and locating system 20 can be modified to provide multiple time slots within each of the seven channels or to provide additional transmission channels to allow for expansion of the tracking and locating system to include a greater number of master and slave units.

[0076] Moreover, if there are two or more master units in same zone, they could interfere with one another. The tracking and locating system 20 can be adapted to account for multiple master units in same zone by assigning different frequency channels to master and slave units, employing time division multiplexing as well as various standards, such as CDMA, or proprietary communications protocols.

Master Unit

[0077] Referring to FIGS. 2 and 2A, FIG. 2 is a block diagram of the master unit 21 and FIG. 2A is a simplified representation of the master unit 21, master units 22-23 (FIG. 1) being configured and operating the same as master unit 21 except for the unique identifying address. The master unit 21 is a transponder unit that includes a data processor 40, a transmitter section 41 that includes an encoder circuit 42 and a transmitter 43, a receiver section 44 that includes a receiver 45 and a decoder circuit 46, and an antenna 47. In addition, the master unit 21 includes a distance measuring unit 48. The master unit 21 further includes input devices, such as a keypad 49 and a microphone 50, and output devices, such as a display unit 51 and a speaker 52. The master unit 21 also includes a Step button 53 and a jack 55 for allowing the operator to use a headset including a microphone and an earphone to hear audible prompts and voice communications. A switch 75 enables the operator to hear synthesized commands generated by the data processor 40 and applied to the speaker 52.

[0078] The microphone 51 and the speaker 52 (or a headset) allow voice communication at least with the other master units, and provides the user's audio interface for receiving audio instructions from the master unit. The keypad 49 allows entry of data and command. The Step button 53 is used by the operator for entering reference point indications that are indicative of how far the operator has walked between reference points during a homing operation when a first search algorithm is being used in accordance with the present invention. The display unit 51 shows the status of a homing operation, provides instructions to the user and other information. The display unit 51 also can display a grid that shows the relative location of master unit 21 with respect to other master or slave units of the tracking and locating system 20.

[0079] In one embodiment, the master unit 21 and the slave unit 31 operate at different frequencies. Preferably, the tracking and locating system 20 of the present invention uses the FCC business bands or unlicensed bands.

master units. Also, the slave unit can include a jack 105 to allow use of a headset. The slave unit 31 further includes a plurality of indicators 69. The slave unit can also include a switch 125 that enables an individual to hear synthesized commands generated by the data processor 40 and applied to the speaker 52. A voice communication request button 170 enables the user to signal a monitoring unit if voice communication is desired.

Implementation of the Master and Slave unit circuitry

[0082] Referring to FIGS. 2 and 3, in one embodiment, the data processing and control functions of the master and slave units can be implemented either in hardware or real-time firmware, or both. In every case, the underlining hardware is 100% digital technology and operates synchronously using a common clock as a source of synchronization. The data (signal) propagation delay of such synchronous hardware designs stays constant, i.e. does not change with temperature, supply voltage variations, etc. The propagation delay can be determined from simulations or a direct measurements. The clock signal can be generated by a crystal controlled oscillator that has very high accuracy and temperature/supply voltage stability down to about 0.001%, for example.

[0083] Similarly, the data encoder 42 of the master unit 21 (and data encoder 62 of slave unit 31) and the data decoder 46 of the master unit 21 (and data decoder 66 of slave unit 31) also include synchronous hardware and exhibit constant propagation delay properties. However, the functionality of the data encoders 42 and 62 and the data decoders 46 and 66 can be implemented in real-time firmware as a part of the data processing and control block functionality.

[0084] On the other hand, the propagation delays of the transmitter sections 41 and 61 and the receiver sections 44 and 64 change significantly with temperature, supply voltage variations, etc., and account for practically all of the variations in the delay times associated with the processing time of master units, such as the master unit 21 and the processing time of slave units, such as

[0080] In one embodiment, the master unit 21 operates in frequency bands of 150MHz and 460MHz, for example. The master unit 21 transmits in the 150MHz band and receives in the 460MHz band. Thus, simultaneous transmit and receive operations can occur. The same is true for slave units, such as slave unit 31 shown in FIGS. 3 and 3A, except that the slave units transmit in the 460MHz band and receive in the 150MHz band. This arrangement is used because it increases the accuracy of distance measurement. In addition, such scheme supports full duplex communications so that a push-to-talk button is not needed. In one preferred embodiment, the operating or carrier frequencies for master and slave units are in the 150MHz and 460MHz frequency bands, other frequency bands in the RF range can be used, as well as frequencies in the infrared or microwave bands, or ultrasonic, for example.

Slave Unit

[0081] Referring to FIGS. 3 and 3A, FIG. 3 is a block diagram of the slave unit 31 and FIG. 3A is a simplified representation of the slave unit 31, slave units 32-34 (FIG. 1) being configured and operating the same as slave unit 31 except for the unique identifying address. In one embodiment, the slave unit 31 is similar to the master unit 21 and is a transponder unit that includes a data processor 60, a transmitter section 61 that includes an encoder 62 and a transmitter 63, a receiver section 64 that includes a receiver 65 and a decoder 66, an antenna 67, and a distance measuring unit 68. In one embodiment, the master units such as master unit 21, and the slave units, such as slave unit 31 shown in FIG. 3, include the same transmitter and receiver sections, but the master unit 21 includes additional components, such as the keypad 49 and the display unit 51, to provide control and monitoring functions. In this embodiment, the slave unit 31 does not include a microphone, but can include a speaker 71 for receiving voice communications from master units. However, in another embodiment, the slave unit 31 can also include a microphone 70, shown by the dashed line, to allow voice communication at least with the

the slave unit 31. The processing time of master units is referred to herein as time T6 and the processing time of slave units is referred to herein as time T3.

Data Transmission Packet Format

[0085] Referring to FIG. 3B, there is illustrated the format for the data packets for communicating between the master and slave units. The data packet includes a Preamble 181, Master and Slave ID fields 182, a Data field 183 and a Postamble 184. The preamble 181 contains a data pattern that enables, or wakes up, the data decoding mechanism of a master or slave unit receiving the signal. The preamble 181 can optionally serve as an automatic gain control (AGC) field to automatically set the signal gain for the receiver of the master or slave unit receiving the signal.

[0086] Referring to FIG. 3C, the Master and Slave ID fields 182 include separate slave ID fields 185 and master ID fields 186. The slave ID fields 185 include a slave ID synchronization pattern 187, a slave ID address mark (AM) pattern 188, a slave ID data field 189, a slave ID cyclic redundancy check (CRC) 190 and a slave ID pad 191. Similarly, the master ID fields 186 include a master ID synchronization pattern 192, a master ID address (AM) pattern 193, a master ID data field 194, a master ID cyclic redundancy check (CRC) 195 and a master ID pad 196. The synchronization and address mark (AM) patterns allow synchronization of the decoder with the incoming data. The cyclic redundancy check (CRC) and the error correction check (EEC) allow the detection and correction (in case of ECC) of errors in the data field. The ID pads are bit patterns that move the decoder to a state, where it is ready to receive the next field or message. The pad also provides the decoder with a time interval to reach this state.

[0087] Referring to FIG. 3D, the Data field 183 includes a data synchronization pattern 197, a data automatic mark (AM) pattern 198, a data field 199, a data error correction check (ECC) or cyclic redundancy check (CRC) 200 and a data pad 201. The synchronization and address mark (AM)

patterns allow synchronization of the decoder with the incoming data. The cyclic redundancy check (CRC) and the error correction check (ECC) allow the detection of errors/correction in the data field. The ID pad are bit patterns that return the decoder to a state and provide the decoder with a time interval to reach this state where it is ready to receive the next field or message.

[0088] Referring again to FIG. 3B, the Postamble places the decoder into a wait or low power consumption state after received data has been processed.

Operating Cycle

[0089] The following general description of the operation makes specific reference to master unit 21 and slave unit 31. However, as is stated above, the description applies to the other master units 22-23 and to the other slave units 32-34. As is stated above, the master unit 21 measures the time between the RF signals to determine the distance between the two (monitoring and child) transponders.

[0090] FIG. 4 is a block diagram of the master unit 21 and the slave unit 31 and illustrating the timing points through the circuits of the master and slave units during signal transmission. The mathematical formula for determining the distance D between two transponders is as follows:

$$D = ((T2+T4)*V)/2 \qquad (1)$$

where T2+T4 is the RF signal round trip time in the air between the master unit 21 and the slave unit 31.

$$T2+T4 = (T-T1-T3-T5) \qquad (2)$$

where:

T is the total elapsed time from presenting the data to be transmitted by the data processing and control block of the master unit, to the reception and

processing of the response (from the slave transponder) by the data processor 40 of the same master unit that initiated the transmission;

T1 is the transmitter path propagation delay from the time the data to be transmitted have entered the data encoder 42 until the signal transmission commences (the modulated RF signal reaches the antenna 47);

T2 is the signal elapsed time of travel between the antenna 47 of the master unit 21 and the antenna 67 of the slave unit 31;

T3 is the processing time of the slave unit 31 (signal propagation delay in the receiver 65 + signal propagation delay in the decoder 66 + data processing time in the data processor 60+ signal propagation delay in the encoder 62 + signal propagation delay in the transmitter 63);

T4 is the signal elapsed time of travel between the antenna 67 of the slave unit 31 and the antenna 47 of the master unit 21;

T5 is the propagation delay over the receive path of the master unit 21 path plus data processing time (signal propagation delay in the receiver 45 plus the signal propagation delay in the decoder 46 plus the data processing time in the data processor 40); and

V is the signal velocity in the open air (3*10^8m/s constant).

[0091] Because the value of V is very large (3*10^8m/s) and the value of D is small (D < 300m), (T2 +T4) << T1 or T3 or T5. As a result, the values of T4, T3 and T5 need to be determined with a high accuracy in order to obtain precise distance measurements. Also,

$$T2+T4 = (T-T1-T3-T5) = (T- T3 - (T1+T5)) \qquad (3)$$

or,

$$T2+T4 = (T-T3 -T6) \qquad (4)$$

where T6 is the sum of T1+T5 which is equal to the processing time of the master unit 21 (i.e., the sum of the signal propagation delays in the receiver 45, the decoder 46, the data processor 40, the encoder 42 and the transmitter 43).

[0092] From equations (1) and (4):

$$D = (T - (T3+T6))*V/2 \tag{5}$$

[0093] Therefore, the values of measurements of the times T, T3 and T6, within a short period of time, can be used to compensate for the impact of variations in the propagation delays.

[0094] Because the propagation delays due to data processing and control functions remain constant, the values of T3 and T6 can be measured during the "loop back" mode of operation. In the loop back mode of operation, the output of the transmitter is connected directly to the input of the receiver, such that the transmitter output signal is forwarded to the input of the receiver via an attenuator. In one embodiment, the data processor 40 (or data processor 60 of a slave unit) places a special test data on the input of the encoder 42 (or 62), starts time measurement (timer) and waits for an output data ready signal provided by the decoder 46 (or decoder 66 of a slave unit). Upon reception of the output data ready signal, the data processor 40 (or data processor 60 of a slave unit) verifies the validity of data and stops the timer. If the data are valid, the data processors 40 (or 60) calculate the times T6 (or T3) by reading the "loop back elapsed time" from the timer and adding the necessary data validation and data processing times.

[0095] In another embodiment, encoder/decoder blocks are not in the path of the ranging signal. Here, the output of the transmitter section is permanently coupled to the input of the receiver section. The data processor 40 (or 60) changes the transmitting frequency to the receiving frequency and enables the distance measuring unit 48 (or distance measuring unit 68 of a slave unit). The circuit generates the ranging signal and performs the distance measuring

function. The results are translated, by the data processor 40 (or 60), back into time delays T3 and T6.

Calibration

[0096] In accordance with the invention, the master and slave units are periodically "calibrated". A test signal is transmitted through the master (and slave) units and the propagation time is measured. In one embodiment, the output of the transmitter section is coupled to the input of the receiver section. During calibration, the transmitting frequency (460MHz) is changed to the receiving frequency (150MHz), for example. This is done under the control of the data processor 40. The output RF filter of the transmitter attenuates the RF signal being supplied to the receiver section.

Distance/Time Measurement Sequence

[0097] Reference is now made to FIGS. 4A and 4Bwhich show timing diagrams illustrating the sequence of. the distance/time measurement events, including calibration. In one embodiment, a one second time cycle time is used to check for the current propagation delay time and to send the ranging signal to the slave unit and receive a reply ranging signal from the slave unit. The ranging signal includes an identification field 182 as shown in FIG. 3B. The transmission also employs error checking, bit checking, etc. A transmission operation can be aborted after a 5 to 10 second delay or timeout, when a reply signal fails to be received from a slave unit to which an interrogation signal has been addressed.

[0098] The master unit 21 sends a command sequence, which, amongst other things, will also wake up the slave unit 31 which is maintained in a low power idle mode by a power saving feature when ranging signal operations are not being conducted. The circuits of the master and slave units operate in a power saver mode in which energizing power is applied to circuits only when necessary for the master and slave units to operate.

[0099] The slave unit 31 performs a "propagation time check" (loopback calibration) and transmits a "delay factor" to the master unit 21. The master unit 21 also performs a propagation time check.

[0100] The master unit 21 receives the reply ranging signal and uses the time of sending the ranging signal, the time of receipt of the reply ranging signal and the constants calculated by the slave unit 31 and the master unit 21 to calculate the distance between the master unit and the slave unit.

[0101] Referring to FIG. 4, the master unit 21 can request a calibration procedure from the slave unit each cycle or request a calibration periodically. This request can be made at any time in the operating cycle. Moreover, the master unit 21 may or may not perform its own calibration with each transmission i.e., cause the test signal to be transmitted through the master unit and to be transmitted to the slave units on a periodic basis.

[0102] In one embodiment, the calibration process is carried out "up front", i.e., at the start of each distance/time measurement sequence, both in the master unit and in the slave unit. The propagation delays of the data processing and control functions propagation delays are known, for example, as a result of device characterization at the factory, and are stored in the memory. These delays remain constant.

[0103] As is indicated in FIGS. 4A and 4B, both the master unit 21 and the slave unit 31 employ timeout windows during portions of the distance/time measurement sequence. When the master unit fails to receive a valid distance/time (ranging) signal (or data sequence) within the time defined by a timeout window, the master unit 21 terminates the distance/time measurement sequence. Thereafter, the master unit 21 makes several attempts to obtain a valid distance/time measurement. If all attempts fail, the master unit 21 enters an error recovery and diagnostics mode and informs the operator by generating appropriate audio and/or visual messages.

[0104] Similarly, when the slave unit 31 fails to receive a valid ranging signal (or data sequence) within the window time, the slave unit 31 terminates the distance measurement sequence and returns to an idle state.

[0105] In a first mode (FIG. 4A), referred to as Option 1, a master unit can enter the loopback mode at the beginning of the distance/time measurement sequence. In a second mode (FIG. 4B), referred to as Option 2, a master unit can enter the loopback mode in the middle of the distance/time measurement sequence.

[0106] Referring to FIG 4A, in Option 1, the master unit 21 enters the loop back mode and calculates the value for T6. During this time, the slave unit 31 is idle. The master unit 21 issues a command (data sequence) to conduct a distance/time measurement with calibration and transmits the command to the slave unit 31. The data processor 40 of the master unit 21 opens a timeout window and waits for a reply from the slave unit 31. The slave unit checks the slave ID data of the incoming signal. If the slave ID data indicates this transmission is intended for slave unit 31, the slave unit 31 enters the loop back mode and calculates the value of T3. The slave unit 31 exits the loop back mode and transmits to the master unit a reply which includes a "Ready" status and the value calculated for T3. 'The slave unit 31 opens the timeout window and waits for the ranging signal. The slave unit 31 also prepares to repeat a ranging signal.

[0107] Upon receiving the "Ready" status signal from the slave unit 31, the master unit 21 responsively receives and stores the T3 value. Then, the master unit 21 starts the "T" count or, in the alternative embodiment using phase detection, enables the distance measurement unit which generates the ranging signal or phases, and transmits the ranging signal sequence to the slave unit. The master unit 21 opens the timeout window and waits for a reply from the slave unit 31.

[0108] The slave unit 31 detects and repeats the ranging signal, i.e. transmits the ranging signal back to the master unit that originated this ranging signal.

The slave unit 31 will detect and repeat the ranging signal each time it is transmitted by the master unit during a distance/time measurement sequence. Thereafter, the slave unit enters an idle state.

[0109] The master unit 21 detects and processes the returned ranging signal and obtains the "T" count or, when phase detection is used, obtains the T value from the time-measurement or distance measurement unit. The master unit 21 calculates distance and checks for possible errors. The slave unit 31 remains idle during this time. The master unit 21 stores the values representing the internal delay for the master unit 21 and the slave unit 31.

[0110] The master unit 21 compares the calculated distance with a "range factor" to determine if the slave unit 31 is within the preset range. If the slave unit 31 is out of range, the master unit 21 activates the location algorithm to locate the position of the slave unit 31. The location calculation uses distance calculation in the location finding procedure.

[0111] Referring to FIG. 4B, in Option 2, the master unit 21 operation begins with the distance measurement command and the master unit 21 enters the loopback mode later in the measurement sequence as is described below. The master unit 21 issues a command to conduct a distance/time measurement (without requesting calibration) and transmits the command to the slave unit 31. The data processor 40 of the master unit 21 opens a timeout window and waits for a reply from the slave unit 31. The slave unit checks the slave ID data of the incoming signal. If the slave ID data indicates this transmission is intended for slave unit 31, the slave unit 31 enters the loop back mode and calculates the value of T3. The slave unit 31 exits the loop back mode and transmits to the master unit a reply which includes a "Ready" status and the value calculated for T3. The slave unit 31 opens the timeout window and waits for the ranging signal. The slave unit 31 also prepares to repeat a ranging signal.

[0112] The master unit 21 responds to the "Ready" status signal received from the slave unit 31 and enters the loop back mode and calculates the value of T6. Then, the master unit 21 starts the "T" count or, in the alternative

embodiment using phase detection, enables the distance measurement unit which generates the ranging signal or phases , and transmits the ranging signal sequence to the slave unit.. The master unit 21 opens the timeout window and waits for a reply from the slave unit 31. The slave unit 31 detects and repeats the ranging signal, i.e., transmits the ranging signal back to the master unit 21 that originated this ranging signal. The slave unit 31 will detect and repeat the ranging signal each time it is transmitted by the master unit during a distance/time measurement sequence. Thereafter, the slave unit enters an idle state.

[0113] The master unit 21 detects and processes the returned ranging signal and obtains the "T" count or, when phase detection is used, obtains the T value from the time-measurement or distance measurement unit. The master unit 21 calculates distance and checks for possible errors. The slave unit 31 remains idle during this time. The master unit 21 stores the values representing the internal delay for the master unit 21 and the slave unit 31.

[0114] The master unit 21 compares the calculated distance with a "range factor" to determine if the slave unit 31 is within the preset range. If the slave unit 31 is out of range, the master unit 21 activates the location algorithm to locate the position of the slave unit 31. The location calculation uses distance calculation in the location finding procedure.

Master Unit

Data Processor

[0115] More specifically, with reference to FIG. 5, in one embodiment, the data processor 40 includes a digital signal processor (DSP) 74, a voltage stabilizer 76, and a battery supervisor 78. The DSP 74 provides the central control for the master unit 21, establishing the operating sequences for the master unit 21 and controlling the components of the transmitter section 41, the receiver section 44 and the distance measuring unit 48 of the master unit 21 during operation of the master unit 21. The DSP 74 includes an analog to

[0119] The digital to analog converter (DAC) 86 forms analog information and control signals under the control of the DSP 74. The frequency converter 88 operates to convert information and control signals produced by the digital to analog converter 86 at frequencies in the range of 100-3400Hz into signals at frequencies in the range of 3500-6800Hz. Switch 89 enables the synthesized speech signals to bypass the frequency converter 88. The information and control signals produced by the encoder are applied to an input of a summing amplifier 96 which passes the control signals to an FM modulator 92 of the transmitter 43.

[0120] The transmitter 43 includes a frequency synthesizer 90, a timing generator 91, embodied as a crystal oscillator, the FM modulator 92, a power output stage 93 and an output bandpass filter 94. The crystal generator produces a clock signal at 10MHz as a time base for the frequency synthesizer 90 which, operating under the control of the DSP 74, produces a carrier frequency signal at 150MHz, for the FM modulator 92. The carrier signal is frequency modulated by the control signals produced by the encoder 42. The output of the FM modulator 92 is connected to the input of the transmitter power stage 93, the output of which is coupled through the output bandpass filter 94 to the antenna 47.

[0121] The transmitter power stage 93 has an associated A/D converter 95 that is operated under the control of the DSP 74 to control the power level of the output power stage 93. The output bandpass filter 94 has a 150MHz central frequency.

<u>Receiver Section</u>

[0122] Considering the receiver section 44, the receiver 45 includes a bandpass filter 100, a receiver front-end amplifier 101, a frequency synthesizer 102, and an FM demodulator 103.

[0123] The input band-pass filter 100 has a passband for passing the 460MHz signal through the front-end amplifier 101 to the FM demodulator 103.

[0124] The frequency synthesizer 102 operates under the control of the DSP 74 for providing synthesized signals at 460MHz less the intermediate frequency value for driving the FM demodulator 103 to recover the low frequency data and voice signals from the frequency modulated 460MHz carrier signals transmitted by the slave units.

[0125] Voice communication signals recovered from received input signals are coupled through a band pass filter 104, having a pass band of approximately 100Hz to 3400Hz, an analog switch 109 and a low-frequency power amplifier 106 which couple voice frequency signals to the speaker 52 when the master unit 21 is operating in the voice mode. The analog switch 109is operated to a closed condition under the control of the DSP 74 during voice mode operation. A received voice frequency power measurement circuit 117 derives from voice frequency signals being extended to the speaker, a signal indicative of the amplitude of the voice frequency signal being received. In addition, switch 75 is connected between a terminal of the analog switch 109 at the input of low frequency power amplifier and the output of the bandpass filter 87, which in turn is connected to the output of the digital to analog converter (DAC) 86. The processor 40 can operate the switch 75, allowing the user to hear synthesized commands generated by the DSP which are routed to the speaker 52 when the switch 75 is operated.

[0126] Information (data) and ranging signals recovered from input signals are coupled through a band pass filter 107 to the distance measurement unit 48 and the decoder 46. The band-pass filter 107 has a pass band of approximately 3500Hz to 6800Hz. Decoder 46 includes a frequency converter 108 which converts the frequency from 3500Hz – 6800Hz to 100Hz – 3400Hz. The output of the frequency converter 108 is applied to the A/D converter 80 for

conversion to a digital signals for use by the data processor 40. The decoder functionality is implemented in firmware.

[0127] Decoder 46 further includes a conventional Received Signal Strength Indicator (RSSI) 119. The RSSI 119 provides an input to the DSP 74 via the A/D converter 80.

[0128] The transmitter 43 also provides for voice communication, as control and ranging signals separated by frequency converters 88 and 108 and filters 98, 104, 107 and 87, between the user and the slave unit 31. To this end, the microphone 50 is coupled to a further input of the summing amplifier 96 through a low frequency amplifier 97, with compression/pre-emphasis, a low pass filter 98 and an analog switch 99. The analog switch 99 is operated under the control of the DSP 74 to enable the user to send voice communications when the master unit 21 is operating in a voice mode.

Antenna

[0129] In one embodiment, the antenna 47 is common for the transmitter 63 and receiver 65 of the master unit 21. However, separate antennas can be provided for the transmitter and receiver, more precise calibration antenna propagation delay is measured as actual loop back versus using a fixed value stored in memory. [0130] Separate antennas provide for more precise calibration because in such embodiment, the antenna propagation delays can be measured during the loop back calibration procedure. In contrast, propagation delay due to a single antenna delay cannot be measured during the loop back calibration procedure. Instead a fixed delay value for the antenna that is factory determined during an initial one time calibration is used.

Distance Measuring Unit

[0131] In this embodiment, an indirect measurement is used in generating and processing the ranging signal to determine the distance between the master unit and a slave unit. In one embodiment, the indirect measurement is obtained by

determining the phase shift phase shift between successive ranging signals. To this end, the distance measuring unit 48 includes a phase detector (PD) 110, an analog inverter amplifier 111, a reference signal generator 112 and analog switches 114, 115 and 116. The phase shift phase shift between successive ranging signals is determined using a voltage controlled oscillator (VCO) 113 and analog switches 114, 115 and 116. The ranging signal received from the slave unit is applied to one input of the PD 110 and compared with a reference signal applied to the other input of PD 110 by reference signal generator 112. The difference (error) signal is applied via A/D converter 80 to the DSP which stores the difference obtained from processing the successive ranging signals.

[0132] The distance measuring unit 48 measures the propagation time of the ranging signal as a function of the phase shift of the signal generated by the VCO 113 which, with other above mentioned components, forms a phase locked loop (PPL) to produce a test or calibration signal for use in determining the internal delay time attributable to circuits of the master unit 21. The analog switches 114, 115 and 116 are operated under the control of the DSP 74 to alter the configuration of the distance measuring unit 48 during calibration to initially synchronize the output of the VCO 113 with the reference signal produced by the reference signal generator 112 or measure the parameters of the PLL, including the PLL gain. When calibration has been achieved, the output of the VCO 113 is connected to an input of the summing amplifier 96 for application to the FM modulator 92. At the same time, the input to the PD 110 is switched to the output of the filter 107. The operation is the same for both ranging signals being transmitted between a master unit and a slave unit or ranging signals being transmitted between one master unit and another master unit.

[0133] In one embodiment, some of the components of the master unit 21, such as the antenna 47, the battery, the LCD display, the keypad, the On/Off switches, the LED, etc., are implemented by hardware components. Other components of the master unit 21, shown as functional blocks in FIG. 5 can be

implemented in hardware and/or processor real-time firmware. In one embodiment, the data processor 40 is embodied as a digital signal processor (DSP). However, the data processor 40 can be some other type of processor or a combination of a processor and an application specific integrated circuit (ASIC), or a processor and standard parts, or a combination of all of the above.

Slave Unit

[0134] Referring to FIG. 6, as is stated above, the slave unit 31 is generally similar to the master unit 31. However, the slave unit 31 transmits in the 460MHz band and receives in the 150MHz band. Moreover, the slave unit 31 responds to but does not initiate homing operations. Also, the slave unit 31 does not include all of the features and functions of the master unit 21 as will be described.

[0135] The master unit 21 and the slave unit 31 include for the most part, the same electronic circuits, and accordingly, the reference numerals given to components of the slave unit correspond to those for like or similar components of the master unit 21, but with "50" added to the reference number. Thus, for example, the input filter 150 of receiver 65 corresponds to the input filter 100 (FIG. 5) of the receiver 45. Some of the differences between the slave unit 31 and the master unit 21 are as follows.

[0136] In one embodiment, the master unit has full control over its slave units, the slave unit 31 does not have a keypad, a display or a display/keypad controller. The interface for the slave unit 31 includes a voice communication request button 170 and light emitting diodes 171, 172 and 173. The light emitting diodes 171, 172 and 173 can indicate, respectively. Moreover, the slave unit does not include a microphone. However, in some applications, it can be desirable for the slave unit 31 to include a display unit and/or a keypad similar to those of the master unit 21.

[0137] In addition, switch 125 is connected between a terminal of the analog switch 159 at the input of low frequency power amplifier 156 and the output of

the bandpass filter 137, which in turn is connected to the output of the digital to analog converter (DAC) 136. The processor 60 can operate the switch 125, allowing the user to hear synthesized commands generated by the DSP which are routed to the speaker 71 (or a headset) when the switch 125 is operated.

Master Unit Operating Modes

[0138] In one embodiment, the master unit 21 has four modes of operation, namely (1) voice communications; (2) Data/command exchange; (3) Distance measurement; and (4) Internal delay measurement/calibration.

[0139] Referring to FIGS. 2 and 5, the system employs modulation bandwidth multiplexing, allowing voice communications, data/command exchange (or distance measurement operations) to be carried out separately. However, these operations can be carried out simultaneously if additional frequency division multiplexing is employed. Referring to FIG. 6X, by way of example, voice communications can be carried out in a first portion 176 of the modulation bandwidth at modulating frequencies from about .3 KHz to 3.1 KHz and data/command exchange and ranging signal transmission can be carried out in a second portion 178 of the modulation bandwidth at modulating frequencies from about 3.8 KHz to 6.5 KHz. However, calibration is carried out in an off-line condition. The DSP 74 enables and disables all of the operations by changing the signal paths in the circuits of the master and slave units during the calibration procedure.

(1) Voice Communication

[0140] Referring TO FIG. 5, initially, the analog switches 99 and 109 are closed. The output signal produced by the microphone 50 is applied to the modulator 92 via the amplifier 97, the filter 98, the now closed switch 99, and the analog summing amplifier 96. The modulator 92 forms an RF signal in the 150MHz band, which is amplified by the power stage 93 of the transmitter 43. The amplified modulated RF signal is passed through the transmitter output

filter 94 to the antenna 47 for transmission to the slave unit 31 (or other master or slave units).

[0141] In the antenna 47, in addition to the transmitted signal in the 150MHz band, there can be a received signal in the 460MHz band from the slave unit 31 or another master or slave unit. The received signal passes through the filter 100, front-end circuitry 101 to the demodulator 103. After demodulation, the demodulated signal passes through the filter 104 and the switch 102 to the amplifier 106. The amplified signal is sent to the loud speaker 52.

[0142] The DSP 74 can also synthesize voice signals and send the synthesized voice signals to the modulator 92 via the DAC 86 and the filter 87, bypassing the frequency converter 88.The DSP 74 can also send synthesized voice signals to the loudspeaker 52 via the switch 75 and the amplifier 106, or in case of slave the DSP 124 sends the synthesized voice signals to the loudspeaker 102 via the switch 125 and the amplifier 156.

<u>(2) Data/command exchange</u>

[0143] The DSP 74 generates command/data signals in a digital format. These signals are sent to the DAC 86 which converts the digital signals to analog signals. These analog signals are sent through the filter 87, frequency converter 88 and the summing amplifier 96 to modulator 92. The modulator 92 forms an RF signal in the 150MHz band, which is amplified by the transmitter power stage 93. The amplified modulated RF signal is passed through the transmitter output filter 94 to the antenna 47.

[0144] In the antenna 47, in addition to transmitted signals in the 150MHz band, there can be data/command received signals in the 460MHz band from slave unit 31 or another master or slave unit. The received signal passes through the receiver input filter 100, the front-end circuitry 101 to the demodulator 103. After demodulation, the demodulated signal passes through the filter 107, the frequency converter 108 and is applied to the input of the ADC 80, which as stated above is integrated into the DSP 74, which processes

the received signal. The frequency converters 88 and 108, as well as the filters 87, 98, 104 and 107 allow simultaneous voice and data/command exchange operations (see FIG. 6X).

(3) Distance measurement

[0145] At initiation of a distance measurement operation, the DSP 74 sets the analog switches 114, and 116 in the upper position and the analog switch 115 into the lower position. In this configuration, the PD 110, the amplifier 111 and the VCO 113 form a phase locked loop (PLL) circuit. As a result, the VCO 113 synchronizes with the reference generator 112. The target slave unit (or another master unit being used as a position reference) closes the analog switch 166 (or 116 in another master unit). The VCO 113 is synchronized when the output of the PD 110, reflecting a 90° phase difference between the signals input to the PD 110 – the derivative of the PD 110 output over time, will be equal to zero.

[0146] When synchronization is achieved, the master unit 21 sends command instructions to the slave unit 31. The slave unit 31 closes the switch 168 in order to route the distance measurement signal from the receiver demodulator output via filter 157 to the input of the transmitter modulator 142 via the summing amplifier 146, so that the signal is looped back immediately and the phase shift is measured by master 21. Similarly, another master unit may close the switch 118 in its distance measuring unit for distance measurement between two master units.

[0147] After confirmation that the switch 168 is closed in the slave unit being addressed (or switch 118 in another master unit), the DSP 74 operates the analog switches 114 and 116 into the lower position and the analog switch 115 into the upper position. This allows the output signal from the VCO 113 to reach the modulator 92 via the summing amplifier 96. The output signal frequency of the VCO 113 is outside of the pass-band of the filter 98. As a result both functions voice communications and distance measurements can be

carried out simultaneously, as described above with reference to FIG. 6X. The action of the analog switch 115 will be explained in the following description of the distance measurement algorithm.

[0148] The amplified, modulated RF signal is passed through the filter 94 to the antenna 47. In the antenna 47, in addition to transmitted signal in the 150MHz band, there can be a distance measurement received signal in the 460MHz band from a slave unit 31 (or another master unit). The measurement received signal passes through the filter 100, front-end circuitry 101 to the demodulator 103.

[0149] After demodulation, the signal passes through the filter 107 and reaches the input of the PD 110. The output of the PD 110 (the phase error signal) is proportional to the phase difference between the measurement received signal and the reference signal being produced by the reference generator 112. This output signal (error signal) is then applied to the input of the ADC 80 and then applied to the DSP 74 as well as to the input of the VCO 113.

[0150] The output signal of the VCO 113 is transmitted to a slave unit 31 or to another master or monitoring unit. In these units, the signal is demodulated and, without any transformation, is applied to the modulator input because the switch 168 in the slave unit 31 (or the switch 168 in another master unit) is closed. As a result, the signal is transmitted back to the master unit 21 that originated this signal in the first place. In the originating master unit 21, this signal is demodulated and applied to the input of the PD 110.

[0151] During this "round trip", the output signal of the VCO 113 is delayed. To the PD 110, this delay appears as a phase shift relative to the phase of the output signal of the reference oscillator 112. The output of the PD 110, that is proportional to this shift, is applied to the input of the amplifier 111, and the output signal provided by amplifier 111 is applied to the VCO 113. The VCO 113 starts changing its frequency proportionally to the output of the PD 110.

This new frequency signal makes another round trip and is applied again to the input of the PD 110.

[0152] The amplifier 111 inverts the signal (180 degree phase shift) provided by the PD 110 so that the VCO frequency is changing in the direction that adds to the phase difference between the PD 110 inputs, instead of reducing it, as in normal PLL operation. By allowing the signal to go through many round trips, the delay of successive RF signals is being accumulated. This allows for a high precision delay measurement with an accuracy that exceeds the actual resolution of the PD 110. During this time, the DSP 74 reads-in, at a periodic time intervals, the values of the output signals (error signals) produced by the PD 110 and stores these values in memory. An algorithm implemented in the DSP 74 determines the round trip delay value from the output of the VCO 113 to the input of the PD 110. In the distance measurement mode, this round trip delay includes internal slave (child) unit 31 and internal master unit 21 (or monitor and monitor transmitter/receiver delays as well as antenna delays; RF signal propagation time between the signal origination monitoring unit and target child or another monitoring unit; and the RF signal propagation time between target child or another monitoring unit and the signal origination monitoring unit during the second leg of the round trip).

Distance Measurement Algorithm

[0153] Referring to FIG. 5, in the initial configuration: without the inverting amplifier 111 and no round-trip delay, the PLL error signal (PD 110 output signal) $\mathbf{E_{PLL}}$ response to a phase step function with an amplitude **a** can be calculated as follows:

$$\mathbf{E_{PLL}} = \mathbf{a}*\exp(-k*t) \qquad (6)$$

where: "k" is the PLL loop gain and "t" is the elapsed time from the applying the phase step. From equation (6), after a certain amount of time, the error

signal E_{PLL} →0 and so the error signal E_{PLL} derivative over time will become infinitely small. As the DSP 74 reads-in, at a periodic time intervals, the values of the error signals E_{PLL} produced by the PD 110 and stores these values in memory, it also calculates the E_{PLL} derivative over time. When the value of the error signal E_{PLL} and its derivative fall below a certain threshold(s), the PLL is synchronized.

[0154] The presence of the round-trip delay D and the inverting amplifier 111 change the PD 110 output error signal (E_{dmeas}) dynamics. With delay D, the error voltage E_{dmeas} cannot be described mathematically in a closed form without certain assumptions: D has to be small (which is the case) and k*D product less than 0.25. With these assumptions the E_{dmeas} values can be calculated as follows:

$$E_{dmeas}=(a/2)*[((B+1)/B)*exp((B-1)/2*D)*t)+((B-1)/B)*exp(-((B+1)/2*D)*t))] \quad (7)$$

where:

$$B = sqrt(1 + 4*k*D) \quad (8)$$

It should be noted that a more precise behavior can be obtained by conducting a simulation.

[0155] After the DSP 74 operates the analog switches 114 and116 into the lower position and the analog switch 115 into upper position, the roundtrip delay will change the phase of the VCO output signal. Mathematically, this change can be represented by the step function with an amplitude

$$a = 2*pi*D/T \quad (9)$$

where: T – is the period of VCO oscillations and pi = 6.28.

[0156] After combining equations (7) and (9), the output error signal (E_{dmeas}) of the PD 110 will be as follows:

$$E_{dmeas} = (pi*D/T)*[((B+1)/B)*exp((B-1)/2*D)*t) + ((B-1)/B)*exp(-(B+1)/2*D)*t))] \qquad (10)$$

[0157] Because $B > 1$, the signal $\mathbf{E_{dmeas}}$ will grow exponentially over time. For a fixed value of k, the signal growth will depend on D value. The $\mathbf{E_{dmeas}}$ values over time t for various D values can be tabulated and stored in the DSP 74 memory in the form of a look-up table.

[0158] The DSP 74 reads-in, at periodic time intervals, the values of signal $\mathbf{E_{dmeas}}$ and compares these values with the values stored in the look-up table. The DSP 74 finds the closest match by calculating correlation values between measured and tabulated $\mathbf{E_{dmeas}}$ vs. t values for different D. The D value that yields the highest correlation between the signal $\mathbf{E_{dmeas}}$ readings (samples) and the tabulated $\mathbf{E_{dmeas}}$ vs. values of **t** is the roundtrip delay value.

[0159] In addition to finding the closest match between the values of signal $\mathbf{E_{dmeas}}$ and t, the DSP 74 can also calculate the $\mathbf{E_{dmeas}}$ derivative (vs. time) values and compare (correlate) these with $\mathbf{E_{dmeas}}$ derivative table.

[0160] For the accurate results, the PD 110, the amplifier 111 and the VCO 113 must operate in the linear region. The DSP 74 is also checking the $\mathbf{E_{dmeas}}$ signal samples against a "saturation threshold". Once the signal $\mathbf{E_{dmeas}}$ exceeds this threshold level, the DSP 74 reconfigures the circuitry of the distance measurement unit into the PLL in order to re-synchronize the VCO 113 and brings the PD 110 output error signal to its initial value.

[0161] The k value can be calibrated/measured in the PLL configuration that is used for synchronization with the reference 112. Under the control of the DSP 74, the reference 112 can be programmed to produce a phase step function with amplitude **a**. The DSP 74 can than obtain the $\mathbf{E_{PLL}}$ samples and compare

(correlate) these samples with the tabulated values of the $\mathbf{E_{PLL}}$ vs. **t** for different values of k.

[0162] The values for the $\mathbf{E_{PLL}}$ and $\mathbf{E_{dmeas}}$ tables can be obtained in the factory and stored in the DSP memory.

[0163] The internal delays of the slave (or child) unit and the master (or monitoring unit) and the transmitter/receiver delays of the sending master unit are determined in the internal delay measurement/calibration mode. Antenna delays can be determined during initial device calibration and a factor, representing the delay attributable to the antenna 47, can be stored for use in subsequent calculations. Alternatively, a delay factor can be automatically included during calibration when dual antennas are used.

(4) <u>Internal delay measurement/calibration mode</u>

[0164] Similarly to distance measurement mode, in the internal delay measurement/calibration mode, the DSP 74 operates the analog switches 114 and 116 from the lower position illustrated in FIG. 5 to the upper position (not shown) in order to synchronize the output signal of the VCO 113 with the output signal of the reference generator 112.

[0165] During the synchronization time, the DSP 74 changes the carrier frequency that is generated by frequency synthesizer 90 from the 150MHz band to the 460MHz band. In addition, the DSP 74 lowers the power of the transmitter output stages 93 by controlling the A/D converter 95. Because the pass-band of the filter 94 is around 150MHz, signals in the 460MHz band from the transmitter output stages is greatly attenuated. This avoids saturation of the receiver front-end 101 without any additional components. In all other modes, the frequency of the signals produced by the synthesizer 90 is set to be within the 460MHz band.

[0166] After synchronization is complete (see above), the DSP operates the analog switches 114 and 116 to the lower position and the analog switch 115 to

upper position. -For this condition, the output signal from VCO 113 reaches the modulator 92 via the summing amplifier 96.

[0167] The same algorithms used in distance measurement mode are used to determine the value of internal round-trip delay time. However, in this case, the round-trip delay time includes the sum of device internal transmitter and receiver delays.

Slave Unit Operating Modes

[0168] The modes of operation for the slave unit 31 are substantially the same as those for the master unit 21. One exception is in the distance measurement mode wherein the switch 168 is used to route the distance measurement signal from the output of the receiver demodulator 153, via the filter 157, to the input of the transmitter modulator 142 via the summing amplifier 146.

Position Determination

[0169] Referring now to FIG. 7, the following is an illustration of one way to determine the position of a target T without using a directional antenna. The distance to the target T is measured at any three points that do not lie in a straight line. For example, in FIG. 7, three points P1, P2 and P3 are located along coordinates X and Y at 90 degrees. Coordinates with angles that are different from 90° can be also used. For three dimensional space, the target is measured at any four points that do not lie in a straight line or in one plane. However, the algorithms for target position determination are the same as for two dimensional space.

[0170] The distance measurements from the target T to points P1, P2 and P3 are R1, R2 and R3, respectively. The target T is located at the point of intersection of three imaginary circles with centers at points P1, P2 and P3 and having radii R1, R2 and R3 corresponding to the distance measurements. Measurements at any two points also will produce a target image Tm, FIG. 7. The three point measurement technique can be used to resolve this ambiguity.

However, this ambiguity cannot be resolved if all three points P1, P2 and P3 lie along a straight line as shown in the example illustrated in FIG. 8.

[0171] For any two circles, such as the circles that have radii R1 and R2, the centers of which lie along the X coordinate, the target coordinate Tx (relative to these three points of measurements) can be calculated as follows:

$$Tx = ((R1)^2 - (R2)^2 + (X12)^2) / (2*X12) \qquad (11)$$

where X12 is the difference between the points (P1 and P2) at which the radii R1 and R2 intersect the X coordinate.

[0172] The value of the target coordinate Ty (relative to these three points of measurements) can be found by substituting X with Tx value and Y with Ty in R1 or R2 circles equations (see below) and solving equation for Ty:

$$(X)^2 + (Y)^2 = (R1)^2, \qquad \text{(for circle R1)} \qquad (12)$$

$$(X - X12)^2 + (Y)^2 = (R2)^2, \qquad \text{(for circle R2).} \qquad (13)$$

[0173] From FIG. 7, it can be seen that for each pair of circles, there are two values of Ty, one for T and the other for its image Tm, a total of four points T and three target image points Tm. For example, from equations (12) and (13) (circles R1 and R2).

$$Ty1,2 = +/- \text{sqrt}((R1)^2 - (Tx)^2). \qquad (14)$$

[0174] Similarly, values for Ty3,4 and Ty5,6 for the two other T/Tm pairs of points can be found from the rest of combinations (see FIG. 7). From FIG. 7, some of the Ty(i,j) pairs will have same Ty(k) value. Similarly, some of the Tx(i,j) pairs will have same Tx(n) value. These identical Ty(k) and Tx(n) values are the real target T coordinates, i.e. Ty(k) = Ty and Tx(n) = Tx. By

comparing all six Ty(i,j) values, the Ty(k) = Ty and Tx(n) = Tx can be found. In the example illustrated in FIG. 7, it is assumed that there is no error in distance measurement. However, in the "real world", there will be an error that is associated with every measurement.

[0175] Referring to FIG. 9, in another example, it is assumed that the worst case error is equal E, and that E is constant, i.e., E does not depend upon the distance. A typical value for E is about two to three meters. From FIG. 9, it can be seen that this error creates an ambiguity zone in this example.

[0176] For the example illustrated in FIG. 9, the ambiguity zone is relatively large. However, The size of the ambiguity zone can be reduced if the relative distance between points P1, P2 and P3 is increased as for the example illustrated in FIG. 10.

[[0177] Referring to FIG. 10, when the distance between points P1 and P3 is increased from 1.75*E to 4*E (point P4), the ambiguity zone is reduced substantially. The width of the ambiguity zone is equal to E and the length of the ambiguity zone is less than 2*E.

[0178] Referring to FIG. 11, similarly, when the distance between points P1 and P2 is increased from 1.9*E to 5*E (point P5), the ambiguity zone is reduced substantially. The width of the ambiguity zone is equal E and the length of the ambiguity zone is less than 2*E for the example illustrated in FIG. 11.

[0179] In the extreme case where the distance between points, such as points P1 and P2, is infinite, the ambiguity zone will be reduced to a square having each side equal to E.

[0180] The processor for each master unit handles all of the algorithm complexities and automates the search process/tracking process. The person operating the master unit 21 during a homing operation needs to perform only a few simple repetitive tasks, such as to move along straight lines and to make only 90° or 180° turns which the operator is prompted to do. In addition to

audio prompts, every prompt can include a display of detailed execution instructions.

[0181] The master units are capable of bringing the operator into a close proximity of a child, within a circle of [sqrt(2)*E] radius. At all times, the operator can monitor other children. This is in stark contrast to the monitoring capabilities that can be provided when various types of directional antenna is employed for homing. When a directional antennas is employed for homing, not only is the operator not be able to monitor other children while homing in on one child, but the operator also is required to have special skills in performing the search because of significant directional errors that are associated with these antennas. Moreover, there have been no attempts to automate the searching process in prior art devices.

Search Algorithms

[0182] The following search algorithms are based on the position determination principles described above. The monitor and slave units support all of these algorithms. In one embodiment, preferably all of the search algorithms are stored in memory of the digital signal processor (DSP) of the master control units, such as (DSP) 74 of master unit 21. The algorithms can be selected by the operator by making appropriate entries using the keypad 49 and the display unit 51 of the master unit 21. Alternatively, the master and slave units can be configured for operation that uses only one (or two) of the algorithms.

<u>Algorithm 1</u>

[0183] The Algorithm 1 is used in the most common case when a child first moves out of an area and then starts meandering around. Reference is made to FIGS. 12 and 13 which illustrate a process flow chart for Algorithm 1 and to FIG. 15 which illustrates an example.

[0184] Referring first to FIG. 15, in the example, it is assumed that a slave, or child unit carried by a child, for example, is at a point T that is out of range of a

master or monitoring unit assumed to be located at a point P1. In response to a monitoring operation, the operator is prompted that the child unit is out of range, and the monitoring unit automatically enters the homing mode. The operator selects a direction and for example, begins moving along a path "Delta (1)" which happens to be in a direction towards a point P2. As the operator walks along this path, the operator depresses the Step button 53 (FIG. 2A) on the master unit once for each step taken. After the operator has walked a distance, such as to point P2, that the value Delta (1) (the distance that the operator has walked) is sufficiently large as to minimize the ambiguity zone, the operator is prompted to stop. The processor of the monitoring unit determines if the value Delta (1) is sufficiently large by determining that the distance between subsequent points Delta (n) is equal or greater than (4 – 5)*E, for example. A desirable Delta (n), which is equal to the difference (P(n-1) – current position), can be also pre-programmed into the processor of the monitoring unit 21. The monitoring unit is storing the current "step count" which is indicative of the distance that the operator has walked along path "Delta (1)". The monitoring unit prompts the operator to go right or left from point P2. In the example, it is assumed that the operator chooses to turn left, which in the example is in a direction away from the location of the target T. The operator begins walking along a path "Delta (2)" towards a further point P3, operating the Step button 53 (FIG. 2A) to register the number of steps taken by the operator along path "Delta (2)". After the operator has walked a sufficient distance along the path "Delta (2)", the operator is prompted to stop and wait for a prompt as to in what direction to head. Assuming that the operator has reached a point P3, the operator is prompted to "Go Back" or to "Go Left", which directs the operator towards the target T. In the example, the operator selects to go left and upon reaching a point P4, the operator is prompted to "Go Left" and so the operator will now be moving in the direction of the target point T. When the operator reaches a point P5, the operator is prompted to stop and is then prompted to "Go in the Same Direction". When

the operator reaches a further point P6, the operator is again prompted to stop and is then prompted to "Go Right", which direction is toward the target point T. As the operator approaches the target point T, the monitoring unit will determine that the target point T, and thus the child being located, is again within range. Moreover, the operator typically will come within sight or hearing distance of the child. The monitoring unit will revert to the homing standby mode. However, if for any reason the operator wants to continue the homing operation, the operator can override the monitoring unit. Other features, options and functions of Algorithm 1 are set forth in the following description of Algorithm 1.

[0185] Step 1 - the Homing Standby Mode. Referring to FIG. 12, after initialization and programming, the monitoring unit enters a homing standby mode, block 240, wherein the monitoring unit periodically measures the distance to the child. The monitoring unit will continuously display "Homing Standby On". The operator can disable the standby mode by entering an appropriate sequence. When the standby mode is disabled, the monitoring unit will continuously display "Homing Standby Off".

[0186] Block 241 determines if the measured distance between the monitoring unit and the child is within a pre-programmed value, i.e., within range, and if so, the operator is prompted to this effect, block 242, and the flow loops back, through block 243, to block 241 and the monitoring unit stays in the homing standby mode and continues periodic distance measurements. The homing mode can be also entered unconditionally by the operator action/request. The monitoring unit is set into the homing mode by depressing a button or entering a sequence using the keypad. Block 243 enables the operator to override the automatic mode and to request entry into the homing mode even when the target child is within range. This also applies to a case when an operator wants to continue homing search even if the child is within the range. The operator enters an appropriate sequence and the monitoring unit 21 continuously displays "Range OFF".

[0187] If block 241 determines that the child is not within range, the monitoring unit prompts the operator and automatically enters the homing mode, block 244, if programmed to do so. After entering the homing mode, the message "Homing On" is displayed on the message display 51 (FIG. 2A). A reset button or reset code entered using the keypad, can be used to reset (unconditionally exit) the homing mode, if desired by the operator. In that case, the message "Homing Off" will be displayed on the message display. With regard to the monitoring range value, it should be noted that the monitoring unit can not conduct the search within the ambiguity zone – within a circle of (sgrt(2))*E. As a result, the monitoring range distance value should not be smaller than the (sgrt(2))*E.

[0188] Step 2-the homing mode. At block 244, the R1 distance (FIG. 7) between the starting point P1 and the target T is measured and the message "Homing ON" is displayed on the display along with the R1 value. This is the first point **P1** of distance measurement.

[0189] In block 245, the R1 measurement is qualified in Step X (FIG. 13), as will be described. Step X qualifies the following events: 1) has the operator moved within the range of the target; 2) has the operator reached the ambiguity zone; and 3) is there an unexpected significant change in the target (child's) position (using statistical approach). Depending upon this qualification outcome, the Step X may or may not continue the flow. In case the flow is continued, the monitoring unit enters Step 3 at decision block 246.

[0190] Step 3. The operator of the monitoring unit enters the "Find next point" mode. The monitoring unit keeps track of number of passes through Step 3, block 246.

[0191] If decision block 246 determines that it is the first time through the Step 3, flow proceeds to block 247 and the monitoring unit prompts the operator with an appropriate message, including "Choose Initial Direction" prompt. The initial direction of walking is not important, the operator can select any direction, block 248. The monitoring unit prompts the operator to

start walking and the operator starts moving in the selected direction, block 249. Alternatively, from block 248, the operator can exit the homing mode, block 250, and the flow returns to the standby mode, Step 1, at block 240. Otherwise (all subsequent times when Step 3 is executed), from block 246, flow proceeds to block 251 and the monitoring unit updates the target position and block 252 prompts the operator with path directions to make one or more of the following choices:

(1) the operator can continue without changing the direction – "same direction";

(2) the operator can make a 90° turn to the right – "right";

(3) the operator can make a 90° turn to the left – "left" or

(4) the operator can make a 180° turn – i.e., "go back".

The latter choice usually is displayed for points **Pn** where n > 3. The position of the target is determined in Step 3 (block 251) when distance measurement values for three points **Pn** become available (**n** = 3). Subsequently, when more then three distance measurement values are available (n > 3), normally the most current three measurements are used to update the target position (provided that these last three measurements do not lie along a straight line, FIG. 8).

[0192] Decision block 253 determines whether there is an unobstructed path. Because of physical obstacles, there can be cases where it can be impossible to choose a direction. In such cases, block 254, the operator shall:

(1) exit the homing and homing standby mode;

(2) move to a new, more open location;

(3) re-start the search, enter Step 1. block 240.

[0193] Otherwise, the operator selects the "same direction" or "right" or "left" or "go back " and positions his or her self accordingly, block 255 and starts following the selected path.

[0194] The operator walks in a straight line, marking every step by pressing and releasing the "Step" button (FIG. 2A) on the monitoring unit. The monitoring unit 21 automatically counts the number of steps.

[0195] Alternatively, an external pedometer device automatically counts the steps taken by an operator in searching for a target, thus eliminating the need for the operator to continuously depress the "Step" button while walking, or completely eliminating the need for a Step button 53 (FIG. 2A). In response to a request by the controller of the monitoring unit, the pedometer electronically transfers the step count to the monitoring unit. The pedometer's step count can be reset automatically upon the monitor unit request.

[0196] At all times that Step 3 is executed, it is important that the operator continue walking close to a straight line. Step length can be programmed into the monitoring unit 21. The monitoring unit 21 can hold step lengths of several operators. In addition, it is important that the operator continue moving in the direction chosen. The monitoring unit 21 can prompt the operator with an appropriate message in this regard.

[0197] Flow proceeds from block 256, Step 4, to block 257 which measures the distance the operator has walked thus far. In this regard, the monitoring unit 21 periodically measures the distance between the monitoring unit and the target unit. Each measurement is qualified in Step X, block 270 (FIG. 13), which qualifies the measurement. Step X may or may not continue the flow. In the cases when Step X continues the flow, in Step 4, the processor of the monitoring unit checks for the next point criteria match – block 257A. If both or one of the following two events occurs:

(1) the difference between the current measurement and the previous distance measurement point R(n-1) value is statistically greater than a certain value, which depends upon E and R(n-1), and is calculated by the processor of the monitoring unit;

(2) the distance between the previous position P(n-1) and the current position is greater than a certain distance, which amongst other things also depends upon E and R(n-1), and is calculated by the processor of the monitoring unit.

[0198] A desirable difference (P(n-1) – current position) can be also pre-programmed into the processor of the monitoring unit 21.

[0199] While executing Step 4, block 257A, the operator may encounter some obstacles, as represented by block 261. If the operator encounters an obstacle, the operator has the following options to deal with these obstacles:

(1) To bypass small obstacles, as represented by block 262, the operator executes a detour routine – block 263 and continues moving in the original direction . While bypassing the obstacle, the operator can stop incrementing the step count until the operator is back on track (direction), after which, the operator can estimate the straight line distance and adjust the count such as by pressing the Step button 53 (FIG. 2A) without making steps, or enter the estimated step count via keypad, which also includes the case of external pedometer;

(2) if it is impossible for the operator to continue in the same direction, the operator can cancel the measurement point search (restart this point search – block 264), recall the previous point state, block 265, and check for an alternative available direction, block 266. If an alternative direction is available, the operator can return back to the previous measurement point and choose an alternate direction, block 267, and continue the next measurement point search, returning to block 256 (Step 4); or, if an alternative direction is not available, from block 266, exit the homing mode, choose and move to a new location, block 268, re-start the search (by re-entering Step 1, at block 240).

[0200] After the "next point criteria match" event has occurred, block 257A, the monitoring unit flow enters Step 5, block 258.

[0201] Step 5. In block 258, the monitoring unit prompts the operator to stop walking. The operator stops walking and acknowledges this event of stopping by pressing a button or, for example, holding the "Step" button depressed for a long period of time. This is the next point of distance measurement Pn. Flow proceeds to Step 6, block 259.

[0202] Step 6. At this time, block 259 causes the monitoring unit to display the Rn value, and the processor of the monitoring unit saves the Rn value and the distance between P(n-1) and Pn, which is equal to:

$$|P(n-1) - Pn| = (step\_count*step\_length) = Delta(n) \quad (15)$$

[0203] Thereafter, flow returns to block 246 and repeats Step 3 to find the next Pn point and the value Rn associated with that point Pn.

[0204] Referring to FIG. 13, a description of Step X is now provided. In block 270, the processor of the monitoring unit evaluates the following possibilities or cases.

[0205] Decision block 271 determines if the distance between the monitoring unit and the child is within a pre-programmed value (within range), the monitoring unit prompts the operator, block 272, and if so, exits the homing mode, block 273, ~~or~~ unless the operator wants to continue the homing operation, block 274. This can be done even if the child is within the range. The operator enters an appropriate sequence and the monitoring unit responsively displays "RANGE OFF".

[0206] In the "RANGE OFF" mode, block 275, if the processor of the monitoring unit has determined that the operator is within the child's ambiguity zone, the monitoring unit displays "Ambiguity Zone Standby", block 276, and the processor checks for the operator request to exit the "Ambiguity Zone Standby" mode, block 277A. If there is no such request the flow returns to the Step 2 (FIG 12, block 244).

[0207] If the master unit has moved into the ambiguity zone, in this mode the operator can move freely and can use other means and/or sensory means, visual, voice, etc., for detecting the child. The monitoring unit processor erases the prior distance measurement points values, but continues the distance measurements to the child (Step 2). When the operator has moved outside of the ambiguity zone, the monitoring unit will enter Step 3, where operator will

be prompted with the "First time message" and the search will be automatically re-started. If, while in the ambiguity mode, the operator wants to exit the "Ambiguity Zone Standby" mode, the operator must enter such request. The processor will check for this request in block 277A . The operator is prompted and the "Ambiguity Zone Standby" mode is exited, block 278A and the flow is returned to Step 1. Note that upon exiting the "Ambiguity Zone Standby" mode, the processor automatically clears any pending homing mode request (unconditionally exits the homing mode).

[0208] If the distance is outside of the range or outside of the ambiguity zone, the processor of the monitoring unit checks to see if the operator decided to re-start the homing process, block 277. In this case the operator is prompted, the homing mode is exited, block 278, and the flow is returned to Step 1.

[0209] If there is no request to re-start the homing process, the processor evaluates the child's position change, block 279. If the position change is qualified, the processor continues the homing operation, block 279A, the monitoring unit continues the flow (return), enters the next step. If after calculations have been carried out, the processor of the monitoring unit has could not qualify the distance measurement data, the monitoring prompts the operator, the homing mode is exited, block 278B, and flow is returned to Step 1. This can occur when the child's position has abruptly shifted and the previously obtained distance measurement data cannot be relied upon.

<u>Algorithm 2</u>

[0210] A process flow diagram for Algorithm 2 is shown in FIG. 12A. Algorithm 2 uses three stationary slave units as position references, which speeds up the target position determination and homing process. At any given point, the monitoring unit 21 can determine its location relative to the virtual coordinates that are formed by these three stationary slave units. As a result, the operator does not need to mark steps by pressing the "Step" button or use the pedometer. Although the operator is prompted to change the direction, the

direction change does not need to be close to 90°, 180°, etc.. This makes it easier for the operator to bypass obstacles, because the operator can cancel the previous (next step) measurements but does not need to return to the previous point or perform distance estimation. In the end, the homing-in process is simplified and allows for the operator's faster movement. Also, the homing-in process becomes obstacle resilient.

[0211] An example of a distance determination process using Algorithm 2 is illustrated in FIGS. 20-22. Referring first to FIG. 20, the relative positions of a child target T and a monitoring unit or searching monitor SM are shown with respect to virtual coordinates X and Y. The positions of the target child T, the searching monitor SM and the three reference slave units C1, C2 and C3 have been rotated for mapping into a display grid. Every position and virtual X,Y coordinate is rotated. However, the relative positions between all of the monitoring units SM, C1, C2 and C3 and the child target T are unchanged. The searching monitor SM at point P1 is separated from child reference units C1, C2 and C3 by distances P1_C1, P1_C2 and P1_C3, respectively. Child reference unit C1 is separated from child reference unit C2 by a distance D12. Child reference unit C1 is separated from child reference unit C3 by a distance D13. Child reference unit C2 is separated from child reference unit C3 by a distance D23. The distances between the child reference units C1, C2 and C3 can be measured (by the searching monitor unit SM) or have fixed values that are entered into a "searching monitor unit SM " during the initialization phase. Also shown are Ck_Y and Ck_X – child reference units C1 – C3 X,Y coordinates. The distances, along the X coordinate between the child reference units C1 and C2 is C2_X and the distance between reference units C1 and C3 is C3_X . The distance along the Y coordinate between C1 and C2 and C3 is C1_Y. The Pny, Pnx (where n=1,2,3, ..) are the X,Y coordinates of the SM points Pn (for simplicity only first point P1 coordinates are shown). These can be calculated from the distances Pn_Ck and the X,Y coordinates for the positions of the child reference units C1-C3. To avoid position determination

ambiguity, the three stationary child units C1, C2 and C3 which are used as reference units preferably should not be located along a straight line as discussed above with reference to FIGS. 7-10, for example. Moreover, the distances D12, D13 and D23 should be large enough to minimize ambiguity error as discussed above with reference to FIGS. 9-11, for example. In one embodiment, the preferable separation distances can be stored in the memory of the master unit and displayed automatically by the searching monitor when entering into Algorithm 2 mode.

[0212] FIG. 21 shows the relative locations between the searching monitor SM, the target and the child reference monitors C1, C2 and C3 after the searching monitor SM has moved a distance Delta 1, from its initial position at point P1 to a point P2 and then a distance Delta 2 from point P2 to a position P3. When the searcher with searching monitor SM reaches point P2, the monitoring unit calculates the position of the searching monitor relative to the virtual coordinates X, Y using distance information provided by the child reference units C1,C2 and C3. As a result, the X,Y coordinates for points Pn (Pny and Pnx) become known. The distance Delta is calculated automatically from the values for Pny and Pnx. The searching monitor provides a prompt "Go right or left". In the example, the searcher has chosen to go right and proceeded to point P3 and the process is repeated. The searching monitor provides a prompt "Go back or go right". In the example, the searcher has chosen return and proceeds to point P4 where the searcher is prompted to proceed. This takes the searcher into the proximity of the target T such that the target child is within range and the searching monitor returns to the homing standby mode.

[0213] FIG. 22 illustrates a variation of the example shown in FIG. 21 wherein the searcher with the searching monitor SM encounters an obstacle upon selecting to go right from point P2. Upon encountering the obstacle, the searcher cancels the original point P2 and continues moving to a new point P2' (also referred to as "New P2" in FIG. 22). In response to the prompt, the searcher again has chosen to go right, and the searcher has bypassed the

obstacle without need to move close to a straight line. The example continues as described above with the searcher continuing to points P3 and P4 and then to the proximity of the target child.

[0214] The process flow chart for this case is similar to that for Algorithm 1 shown in FIGS. 12 and 13 and blocks of the process flow diagram for Algorithm 2 have been given the same reference numbers as corresponding blocks of Algorithm 1. Referring to FIG. 12A, the process of Algorithm 2 is similar to that of Algorithm 1 for Steps 1-3, blocks 240-255. Step 4 is entered via block 280. Block 257 provides distance measurement and checking for Step X conditions in the manner of Algorithm 1 (FIG . 13). Then, flow proceeds to block 257A which provides next point criteria match as for Algorithm 1. After the "next point criteria match" event has occurred, block 257A, the monitoring unit flow enters Step 5, block 258 and continues to Step 6, at block 259, and returns to Step 3 as for Algorithm 1. Alternatively, if block 257A determines that a next point criteria match event has not occurred, flow proceeds to decision block 281 which checks for an obstacle. Block 282 determines if an obstacle can be bypassed or not. If so, flow proceeds to block 283 which cancels the previous point measurements and, at block 284, allows direction to be changed and the flow is returned to block 257. If block 282 determines that the obstacle cannot be bypassed, flow proceeds to block 285 which exits the homing mode and the operator must chose a new location and restart the homing process. Flow is returned to Step 1, block 240 (FIG. 12A).

Algorithm 3

[0215] Referring to FIG. 14, which is a process flow diagram for Algorithm 3, Algorithm 3 can be used in high speed search and rescue operations, tracking multiple children, as well as coordinated team search, etc. An example of a distance determination process using Algorithm 3 is illustrated in FIGS. 16-19. Referring first to FIG. 16, the relative positions of a child target T and a monitoring unit or searching monitor SM are shown with respect to virtual

coordinates X and Y. The child virtual coordinates are Ty and Tx. The virtual coordinates for the searching monitor are SMx and Smy. In this example, Algorithm 3 employs three stationary master units M1, M2 and M3 as reference units as shown in FIG. 16, for example. Reference unit M1 is separated from reference unit M2 by a distance D12. Reference unit M1 is separated from reference unit M3 by a distance D13. Reference unit M2 is separated from reference unit M3 by a distance D23. The distances between the searching monitor SM and the reference units M1, M2 and M3 are SM_R1, SM_R2 and SM_R3, respectively. The distances between the target T and the reference units M1, M2 and M3 are T_R1, T_R2 and T_R3, respectively. To avoid position determination ambiguity, the three stationary master units M1, M2 and M3 which are used as reference units preferably should not be located along a straight line as discussed above with reference to FIGS. 7-10, for example. Moreover, the distances D12, D13 and D23 should be large enough to minimize ambiguity error as discussed above with reference to FIGS. 9-11, for example. In one embodiment, the preferable separation distances can be stored in the memory of the master unit and displayed automatically by the searching monitor when entering into Algorithm 3 mode.

[0216] With reference to FIG. 14, the process is entered into in Step 1, block 290, which enables the homing standby mode. As described above for Algorithms 1 and 2, the monitoring unit or searching monitor periodically checks the child monitoring units to determine whether all of the children being monitored are within the prescribed range. Whenever a child moves out the prescribed range, the homing algorithm is automatically initiated. Step 2, block 291, determines if reliable communication can be established between the searching monitor SM and the reference units M1, M2 and M3, as well as between reference units M1, M2, M3, the searching monitor SM and the target T. If not, the operator moves to a new location, as represented by block 292

and the flow returns to block 291 to determine if reliable communications can now be provided between the searching monitor and the reference monitors.

[0217] When reliable communications are established, flow proceeds to decision block 293 which determines whether the children being monitored are within the prescribed range. If so, the searching monitor provides a suitable prompt to the operator, block 294, and flow normally returns through block 295 to block 291. Blocks 293-295 form a wait loop that continuously monitors the child units to detect when a child being monitored moves of range, block 295 enables the operator to force entry into the homing mode.

[0218] When a child moves out of range, or if forced entry into the homing mode is requested by the operator, flow proceeds to Step 3, block 296, which obtains the searching monitor and child unit distances relative to the reference units M1-M3. The distances between the reference units M1, M2 and M3 can be measured (by the monitoring units themselves) or have fixed values that are entered into a "searching monitor unit" during the initialization phase. The three position reference units M1, M2 and M3 do not have to be stationary. For example, members of a search team can carry these units, the members of the search team may be moving relative to one another in conducting the search. Whether the units are stationary or not, there may be three or more monitoring units in the field. As result, at any given moment, a combination of any three monitoring units can be used as the position reference. Such arrangement can be used for conducting multiple simultaneous automated high-speed searches. It is also impervious to obstacles and is very precise. One possible application is for locating individuals in a theme park. Other possible applications include a search and rescue operation that has to be conducted in a very short time and or at high speed, or a search operation at a school outing when only a few master units are monitoring a large number of children.

[0219] Flow proceeds to Step 4, block 297, which determines the relative distance between the searching monitor and the unit carried by the target child. In response to a request initiated by a user of a master unit 21, the three position

reference units provide outputs indicative of the distance between all master units as well as distance between master units M1, M2 and M3 and target children, such as child target T. Based upon this information, the positions of all reference units M1, M2 and M3 and target children are calculated relative to "virtual" coordinates that are formed by any three monitoring or reference devices M1, M2 and M3. The virtual coordinates are mapped into a grid so that the relative positions between all monitoring units and the target or targets relative to each other is displayed on the grid, block 298, as well as the positions of other reference or monitoring units.

[0220] Digressing, with reference to FIG. 17, the positions of the target child T, the searching monitor SM and the three reference units M1, M2 and M3 have been rotated for mapping into a display grid. Every position and virtual X,Y coordinate is rotated. However, the relative positions between all of the monitoring units SM, M1, M2 and M3 and the child target T are unchanged. Mn_Y and Mn_X (where n = 1, 2, 3) are stationary reference virtual coordinates. The coordinates of reference units M1, M2 and M3 can be calculated from the distances D12, D13 and D23. The coordinates Ty and Tx for the target child T can be calculated from the distances T_Rn and the coordinates Mn_Y and Mn_X of the reference units M1, M2 and M3(where n = 1, 2, 3). The coordinates SMy and SMx for the searching monitor SM can be calculated from and the coordinates Mn_Y and Mn_X of the three reference units M1, M2 and M3 and the distances SM_R1, SM_R2 and SM_R3.

[0221] Referring again to FIG. 14, flow proceeds from block 298 of Step 4 to Step 5, block 299, which evaluates conditions such as whether the child is within range, block 300, and whether the distance between the searching monitor and the target unit calculated is within an ambiguity zone, block 304. If block 300 determines that the child is outside of the range, flow returns to Step 2. Otherwise, the child is within range, the operator is prompted to that effect, block 301, and flow proceeds to decision block 302 which determines whether the operator has forced the homing operation. If the operator has not

forced the homing mode and if the child is now within range, the homing mode is exited, block 303, and flow returns to Step 1 to await the next time a determination is made that a child has moved out of range. If the operator has forced the homing mode, flow proceeds to decision block 304 which determines whether the distance calculated places the searching monitor within the ambiguity zone. If the searching monitor is not within the ambiguity zone, flow returns to Step 2. If block 304 determines that the searching monitor is within the ambiguity zone, the operator is prompted, block 305, prior to the flow returning to Step 2.

[0222] Referring to FIG. 18, the virtual coordinate information allows the searching monitor and target to be mapped onto a display grid of the master unit 21. In one embodiment, illustrated in FIG.18, only relative positions for the child target and the searching monitor SM, including the initial position for the searching monitor SM, are displayed. Also, the relative positions of other child units C1 and C2 can be shown. In the case of three stationary monitoring or reference units M1, M2 and M3, optionally, these may or may not be displayed on the grid shown in FIG, 18. In addition, the original in-range circle 25 (FIG. 1) and the original position of the searching monitor SM (which can correspond to master unit 21 in FIG. 1) can be displayed on the grid as shown in FIG. 18. The scale of the display can be set automatically or be set by the operator.

[0223] The "searching monitor SM" can determine it's own position relative to the reference units M1, M2 and M3 as well as the target's position relative to the reference units M1, M2 and M3. Consequently, the searching monitor SM can also determine its own position relative to the target child without a need for establishing its own three-point coordinates for the example for three stationary master units M1, M2 and M3 shown in FIGS. 16, 17 and 18. As a result, a searching monitor SM need not move in a pattern.

[0224] Although there are many possible ways of defining virtual coordinates, in every instance, the result will be the same. Also, the "virtual" coordinates do not need to be displayed on a grid.

[0225] It should be noted that several search operations are carried out simultaneously (three simultaneous operations are shown in FIG. 19). The accuracy of measurements does not depend upon the speed of the target. Also, displaying on a "grid" the position of the searching monitor SM and the positions of the other monitoring units relative to the position of the target or targets, gives operator the ability to perform an interactive search, no matter what the speed of the target or targets. This also improves productivity as only few operators can oversee many children (see FIG. 19). FIG. 19 shows an example of the use of the homing Algorithm 3 when the reference monitors M1-M3 are moving. However, a stationary reference unit, such as a stationary child unit CU, is located at the center of the "range" circle 25. M1_I, M2_I,and M3_I, represent the initial positions of the reference monitors M1, M2 and M3, and M1_C, and M3_C, represent current positions of the reference monitors M1- and M3, respectively (reference monitor M2 not having moved) SM_I is the original position of the searching monitor SM and SM_C is the current position of searching monitor SM. D1 is the distance from the current position of the searching monitor and the target T1, D2 is the distance from the current position of the monitor M1 and the target T2. The manner in which these are determined is similar to that described above for the example in which the locations of the reference monitors M1,M2 and M3 are fixed. Also, the traces (consequent positions) of monitors M1-M3, searching monitor SM and target child units T1 and T2, as well as anticipated direction(s) of movements of these units are displayed. The master unit 21 can also improve the target position determination accuracy by combining its own measurements with the measurements of the other monitoring unit 21.

[0226] Similarly, several operators can organize a coordinated search for a very fast moving target, a target that is moving faster than an operator, as

positions of the target and all monitoring units participating in the search can be displayed on the grid (see FIG. 19) Also, a few master units can effectively monitor many children.

[0227] As is stated above, FIG. 19 illustrates the case where the position reference monitoring units are moving. Here one monitoring unit 21, for example, a team leader, (shown as "searching monitor unit" SM), periodically requests distance measurements from other three moving monitoring or reference units. The searching monitor unit SM processes the information in a similar fashion that is in case of three stationary monitoring units, and broadcasts the display information to the other monitoring or reference units (shown as M1, M2 and M3). This allows providing a coordinated search for a single child or a plurality of children. When all of the reference monitoring units are moving, there is a chance that at some point, the reference units M1, M2 and M3 (or two of the reference units and the searching monitor SM) might end located along a straight line. However, as described above, the searching monitor SM displays the relative positions of the reference units and so the traces will indicate to the searcher that the reference units are moving in directions toward alignment along a straight line. In such case, the searcher can send a voice communication to the reference units to warn the other operators to change the direction in which they are moving..

[0228] It should be noted that several groups of monitoring units can conduct a simultaneous independent search for multiple targets. Because all of the monitoring units are moving, the original in-range circle position cannot be preserved unless a stationary slave unit is used as position reference. In such case, the original in-range circle can be displayed in proper relation to the positions of all of the monitoring units and the target units carried by children.

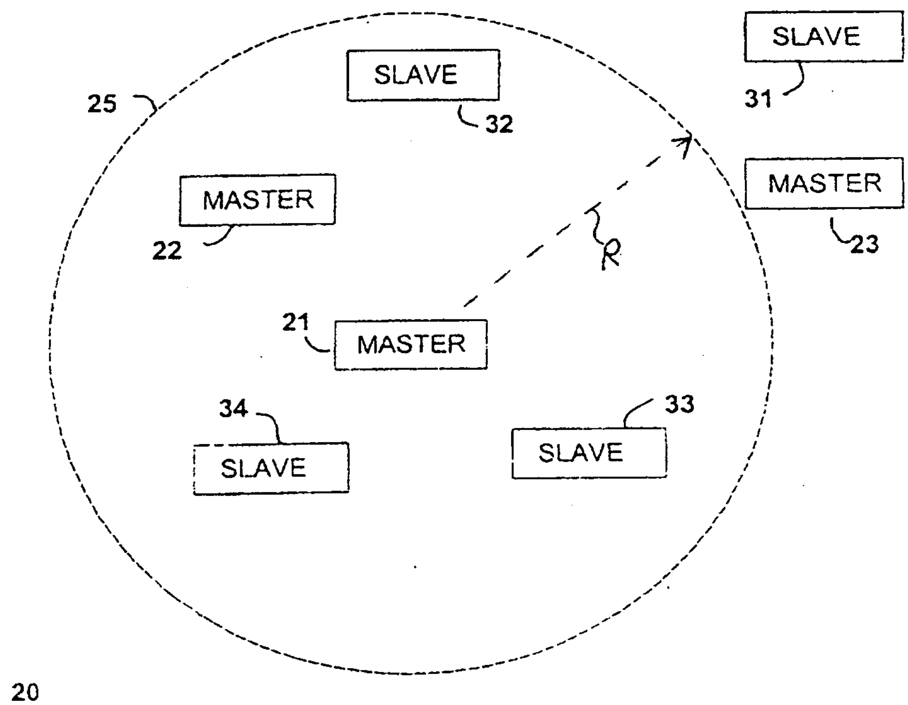
[0229] As is known, global positioning systems can determine the location of a "sending device" to within about 50 – 100 meters and in certain environments (covered/enclosed buildings, dense forest, bad weather, etc.) cannot operate at all. In a further application, the tracking and locating system 20 of the present

invention can be seamlessly integrated. This is because the present invention search Algorithms 1-3 can seamlessly (under device processor control) operate on distance measurement data obtained by the present invention technology as well as data obtained by the GPS-based technology, or both. Thus, providing the operator with a unified man-machine interface, as described in the present invention, regardless of technology that is used to collect the position data. In the end, the user gets the best of both worlds as such system will work in adverse environments and, on a very cost effective per person basis, provide tracking and location functionality with an easy to understand the present invention graphical user interface (GUI). In applications which include GPS-based technology, the operation of the tracking and locating system 20 can be similar to that described above using the homing Algorithms 1-3. In another application, the slave electronics can be embedded into an object or a document, for example, a golf ball. In this application, the slave unit is stripped of all man-machine peripherals and interfaces (such as keys, microphone, speaker or headset plug, LEDs, switches, etc.) and its electronics are integrated together with a tiny rechargeable battery into a golf ball. The battery can be re-charged without contact using an electromagnetic field, for example. A micro-machined switch that is turned on by a certain acceleration forces is used as a power-on switch. This switch can turned off in response to a command signal transmitter by the master or monitoring unit. When the golf ball is hit with a force that exceeds a certain threshold, the power switch is turned on, powering the embedded electronic circuits. In this application, the operation of the golf ball tracking and locating system 20 in locating golf balls can be similar to that described above using to the homing Algorithms 1-3.

[0230] Although exemplary embodiments of the present invention have been shown and described with reference to particular embodiments and applications thereof, it will be apparent to those having ordinary skill in the art that a number of changes, modifications, or alterations to the invention as described herein may be made, none of which depart from the spirit or scope of the

present invention. All such changes, modifications, and alterations should therefore be seen as being within the scope of the present invention.

FIG. 1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SLAVE
32
25
MASTER
23
MASTER
22
R
21
MASTER
34
SLAVE
33
SLAVE
20

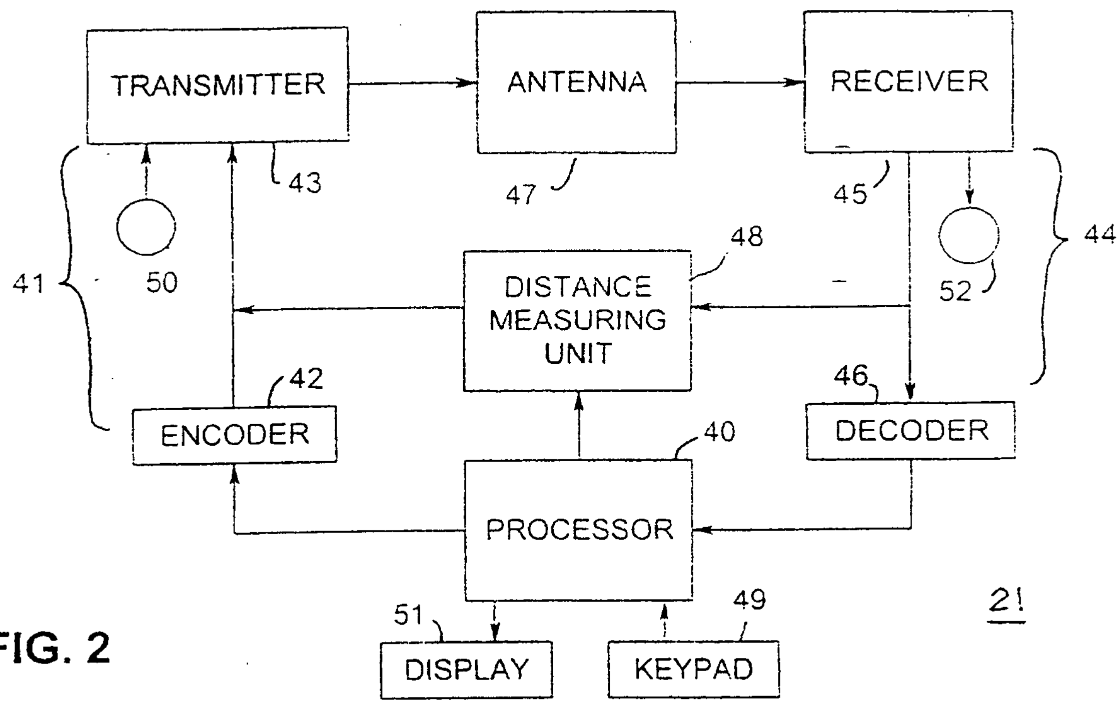
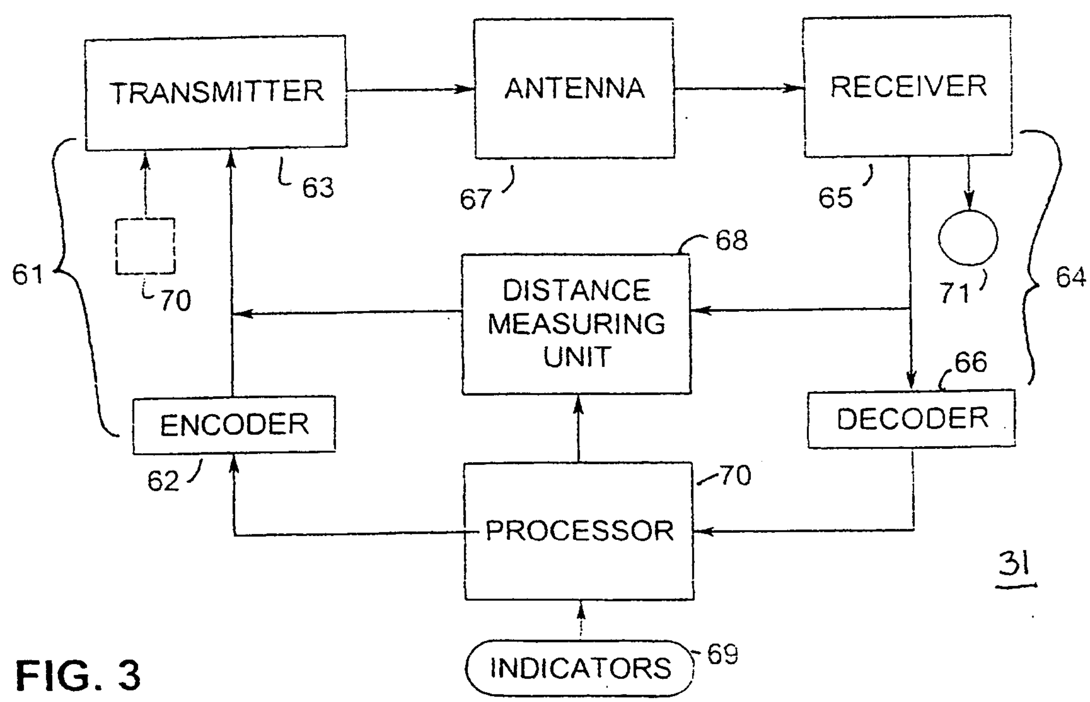

TRANSMITTER
ANTENNA
RECEIVER
43
47
45
44
41
50
52
48
DISTANCE MEASURING UNIT
42
ENCODER
46
DECODER
40
PROCESSOR
51
49
DISPLAY
KEYPAD
21

FIG. 2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61
70
71
64
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DISTANCE MEASURING UNIT
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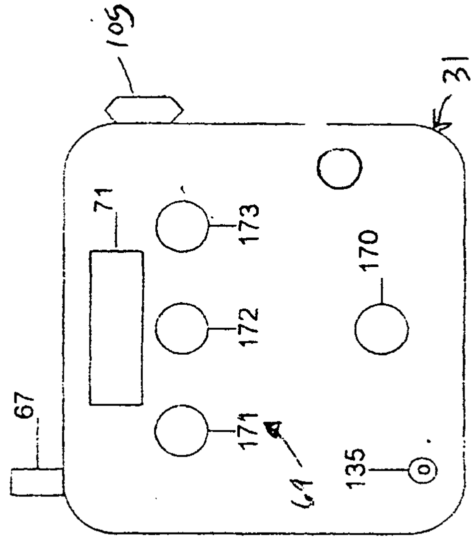
ENCODER
DECODER
62
70
PROCESSOR
31
INDICATORS
69

FIG. 3

FIG. 3A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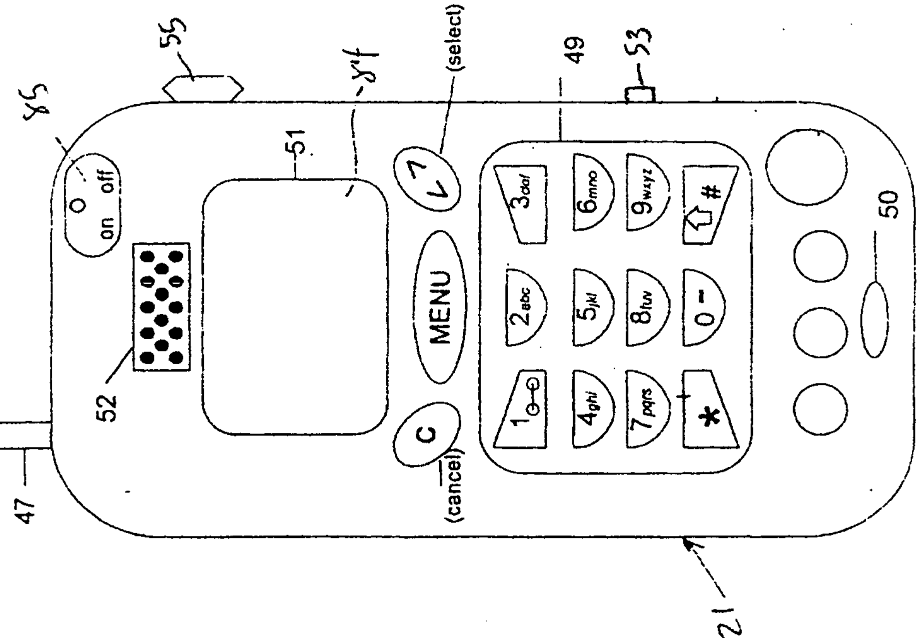
71
173
172
171
170
67
135
61

FIG. 2A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85
54
51
(select)
49
53
on off
MENU
52
47
C
(cancel)
50
21
1
2abc
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9wxyz
0
*
#

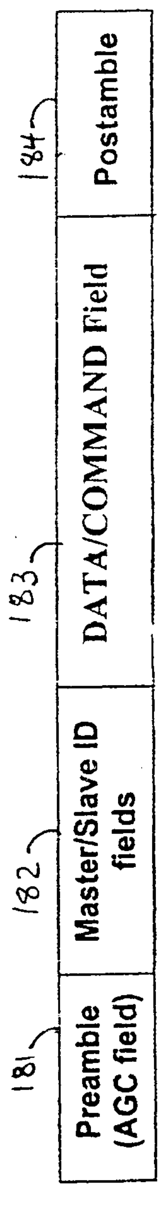


FIG.3B

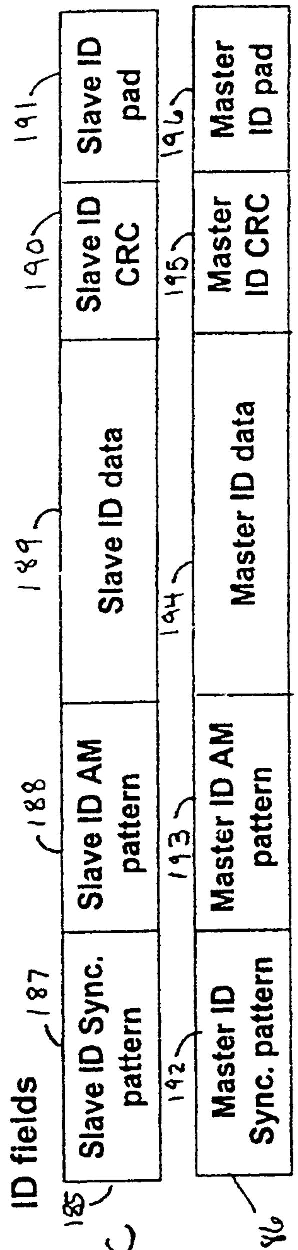


FIG.3C

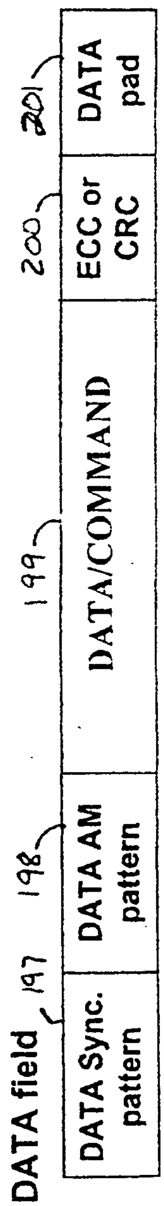


FIG.3D

FIG. 4

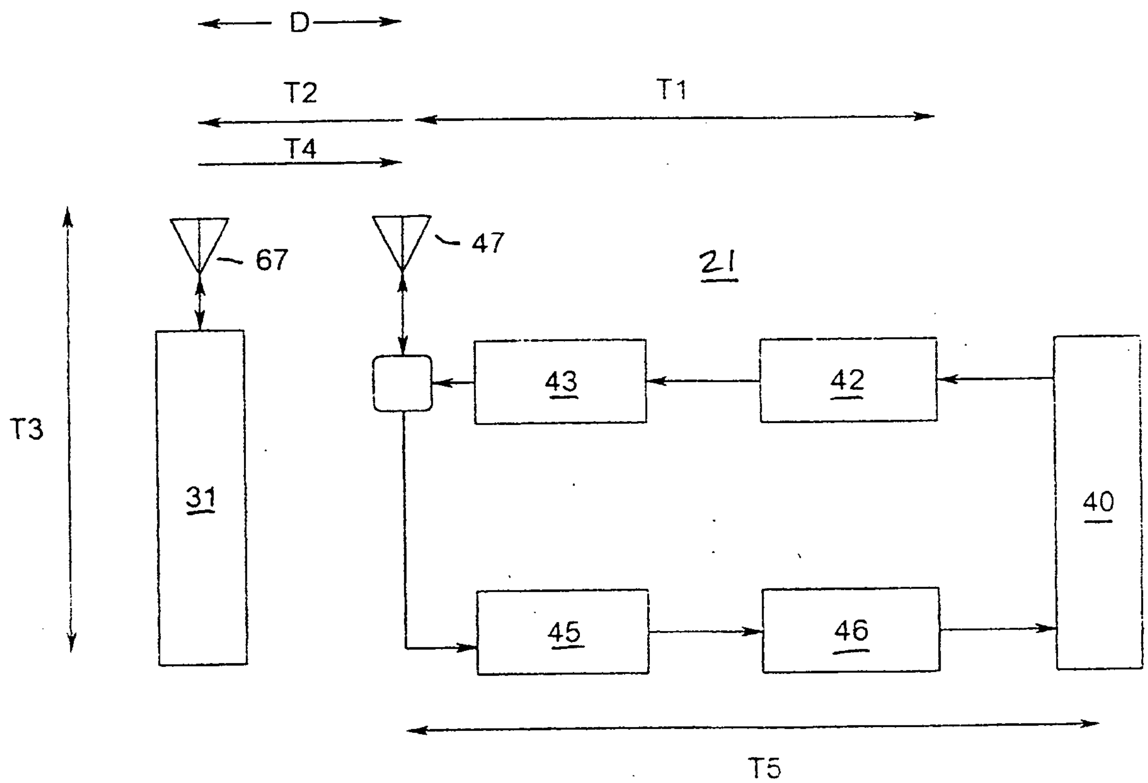


FIG. 4A

DISTANCE/TIME MEASUREMENT SEQUENCE - OPTION 1

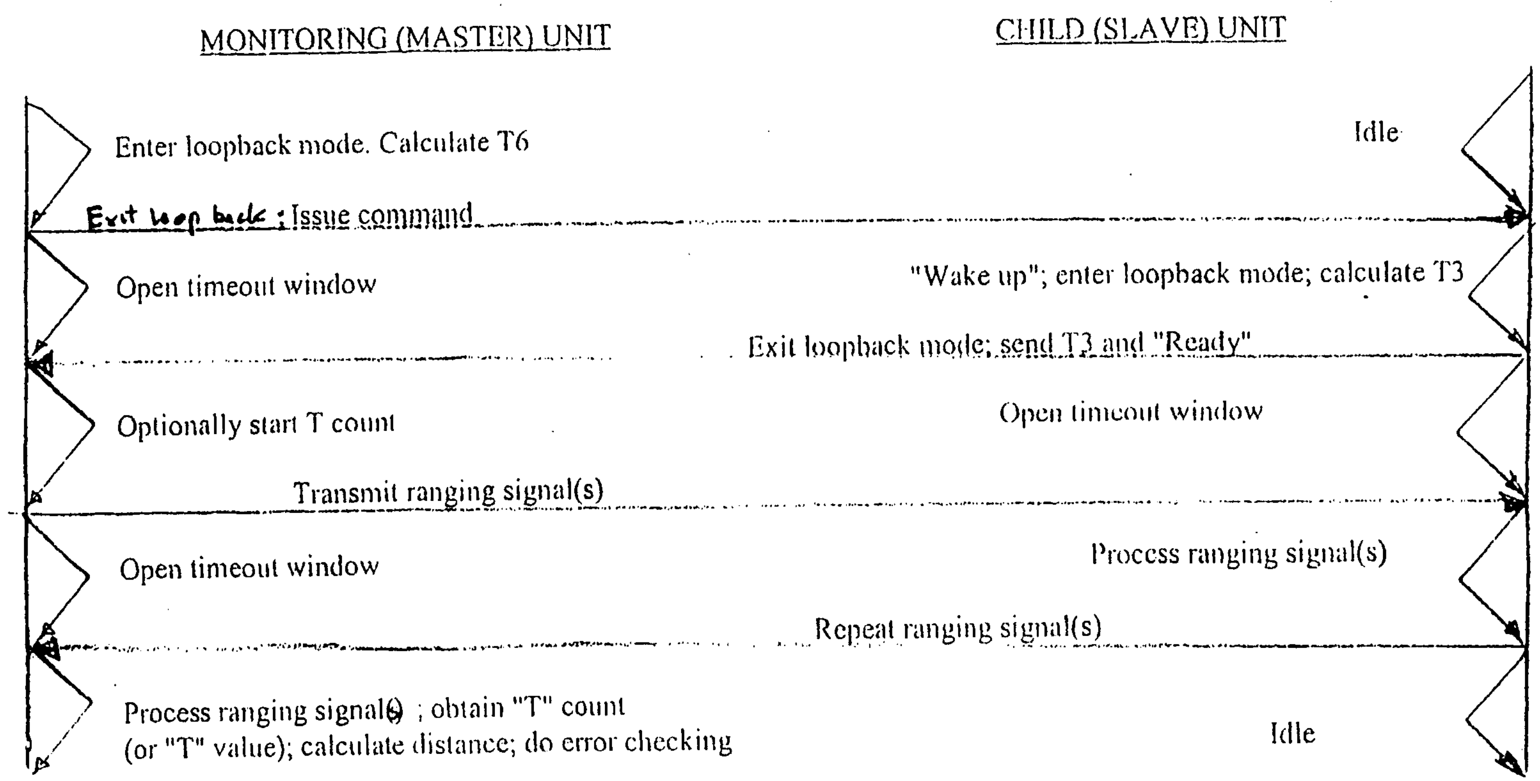


FIG. 4B

DISTANCE/TIME MEASUREMENT SEQUENCE - OPTION 2

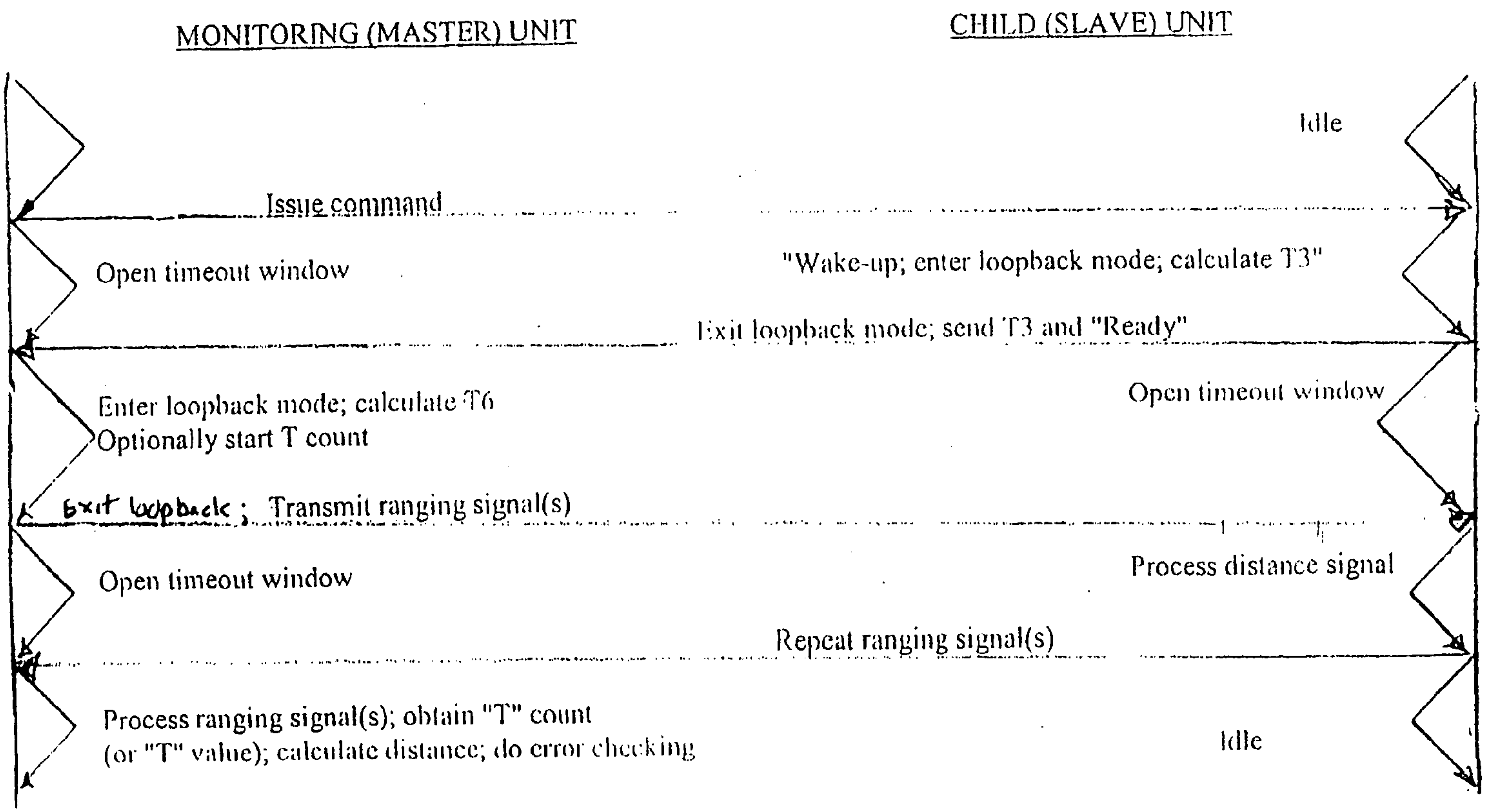


FIG. 5

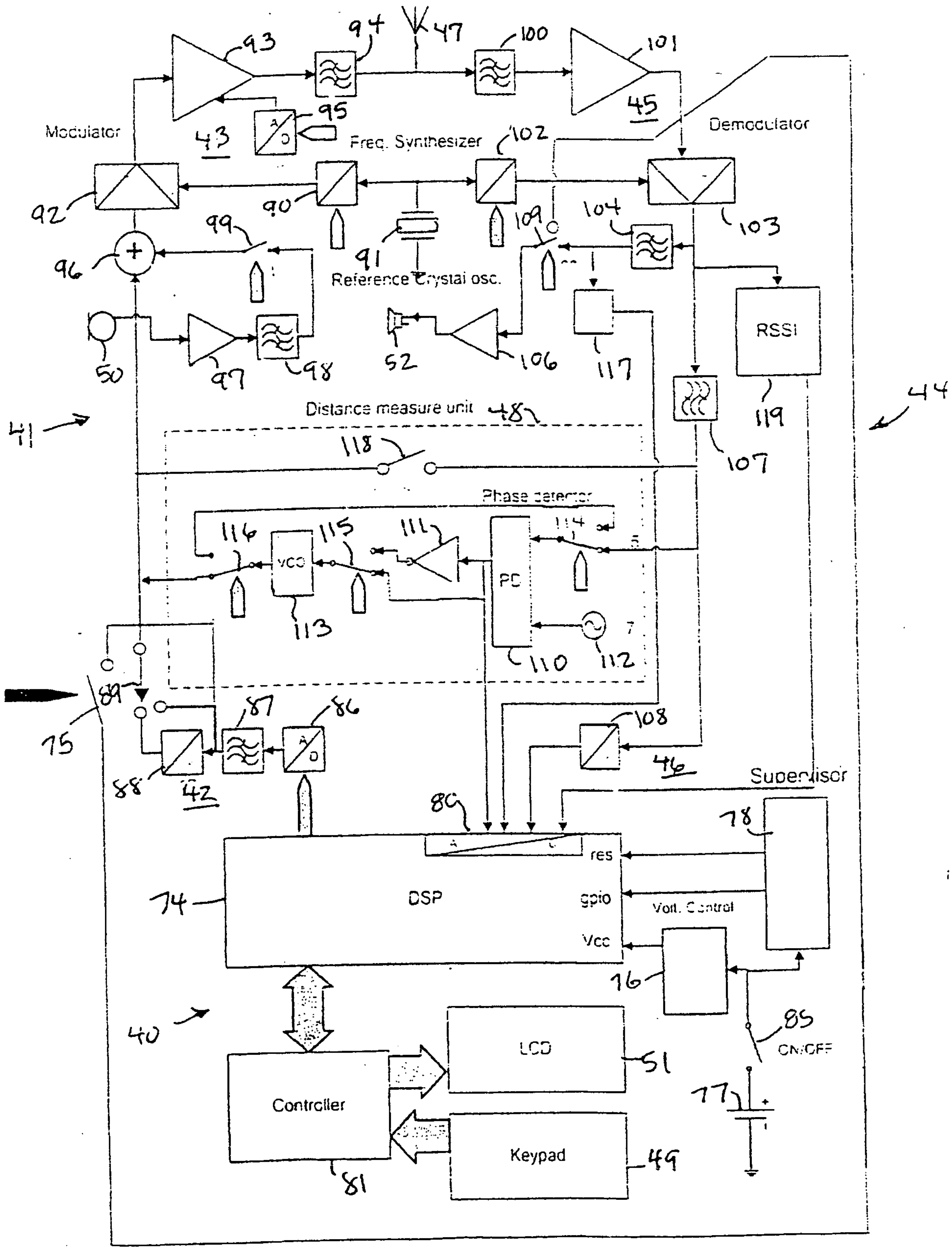
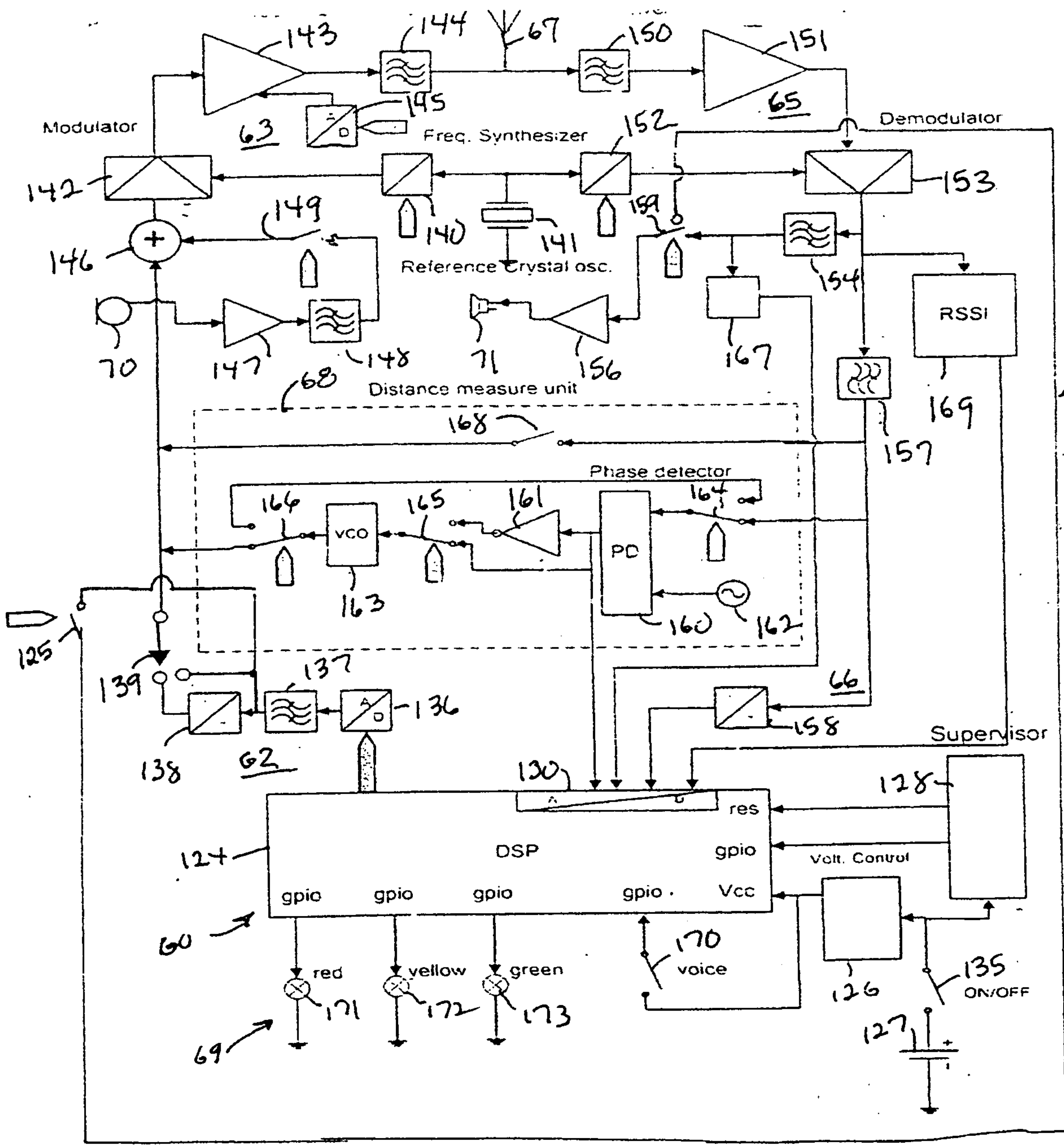

Modulator
Freq. Synthesizer
Demodulator
Reference Crystal osc.
RSSI
Distance measure unit
Phase detector
VCO
PD
Supervisor
DSP
res
gpio
Volt. Control
Vcc
LCD
ON/OFF
Controller
Keypad

FIG. 6


143
144
67
150
151
Modulator
63
145
Freq. Synthesizer
152
65
Demodulator
142
140
141
159
153
146
149
Reference Crystal osc.
154
RSSI
70
147
148
71
156
167
64
68
Distance measure unit
169
168
157
Phase detector
166
165
161
164
VCO
PD
163
160
162
125
139
137
136
66
138
62
158
Supervisor
130
res
128
124
DSP
gpio
Volt. Control
gpio
gpio
gpio
gpio
Vcc
60
170
voice
red
yellow
green
126
135
ON/OFF
171
172
173
127
69

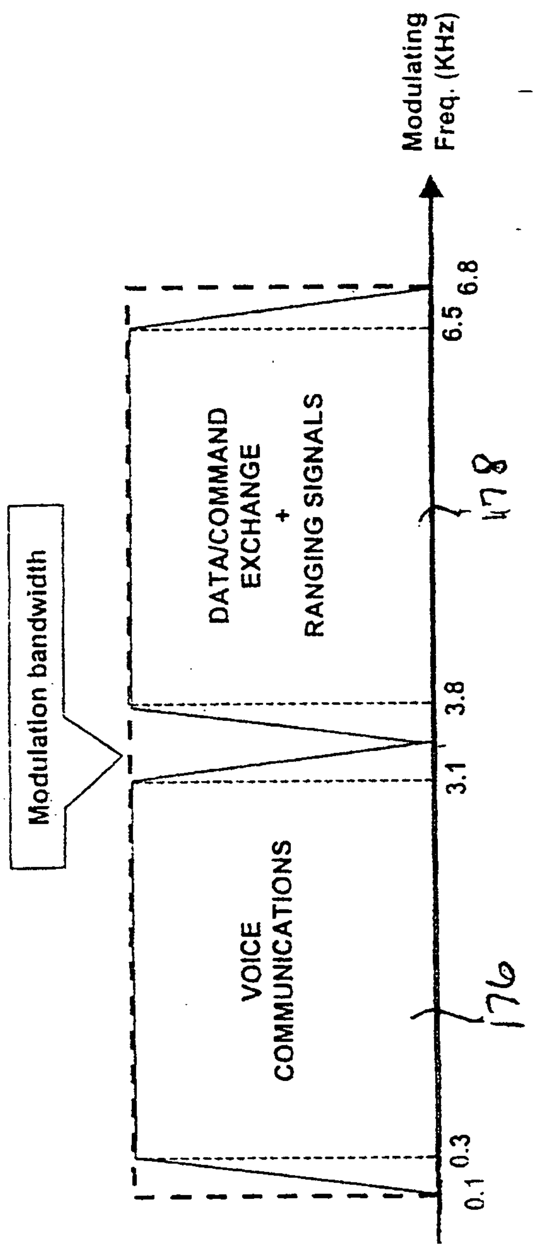

Modulating Freq. (KHz)
Modulation bandwidth
VOICE COMMUNICATIONS
DATA/COMMAND EXCHANGE + RANGING SIGNALS
176
178
0.1
0.3
3.1
3.8
6.5
6.8

Fig. 6X

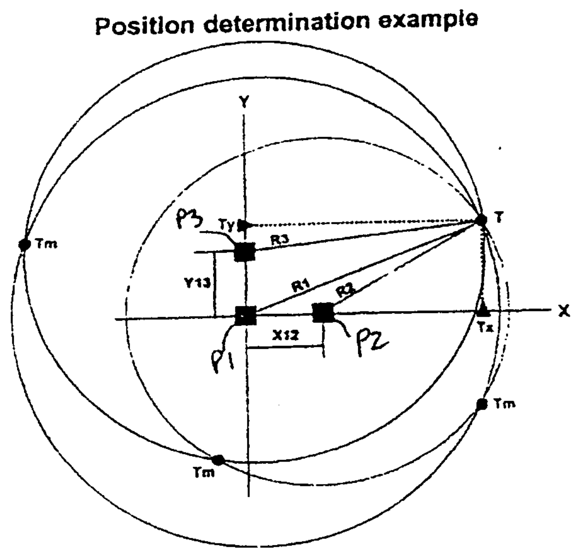

Position determination example
Y
X
T
Ty
Tx
Tm
Tm
Tm
Tm
R3
R1
R2
Y13
X12
P3
P1
P2

FIG. 7

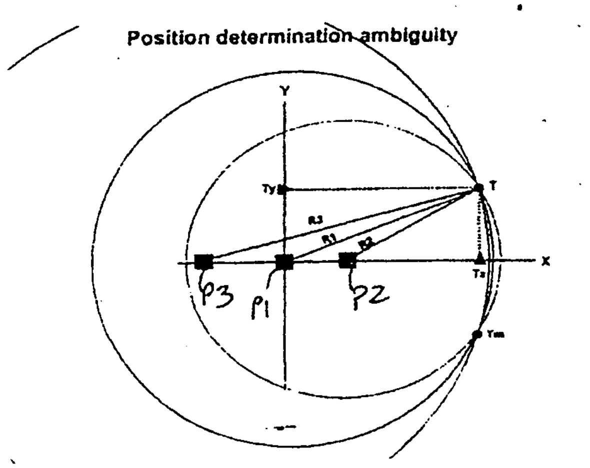

Position determination ambiguity
Y
X
T
Ty
Tx
Tm
R3
R1
R2
P3
P1
P2

FIG. 8

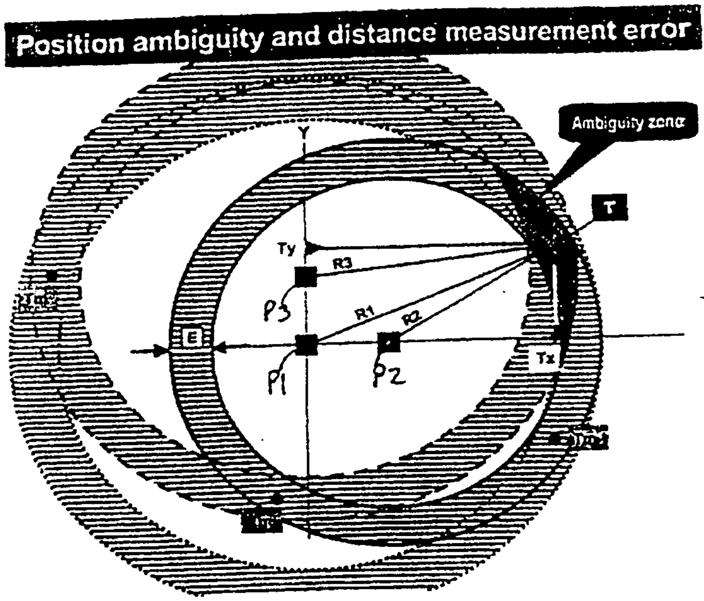

Position ambiguity and distance measurement error
Ambiguity zone
T
Y
Ty
R3
P3
R1
R2
E
P1
P2
Tx
X

FIG. 9

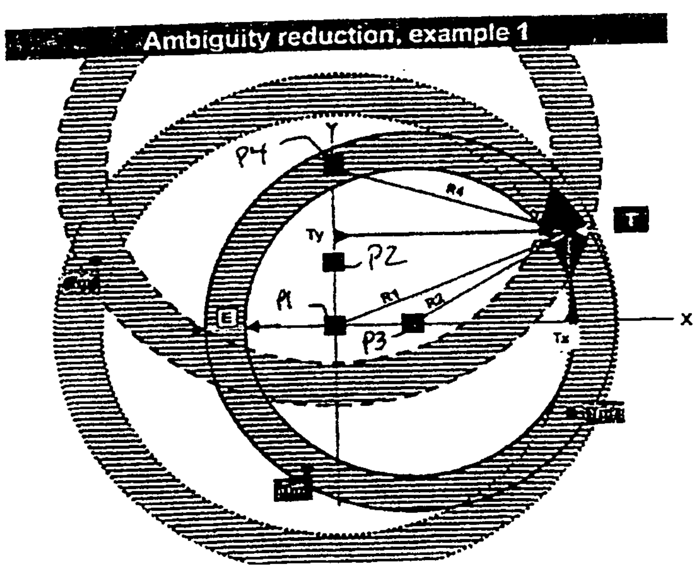

Ambiguity reduction, example 1
Y
P4
R4
T
Ty
P2
P1
R1
R2
E
P3
Tx
X

FIG. 10

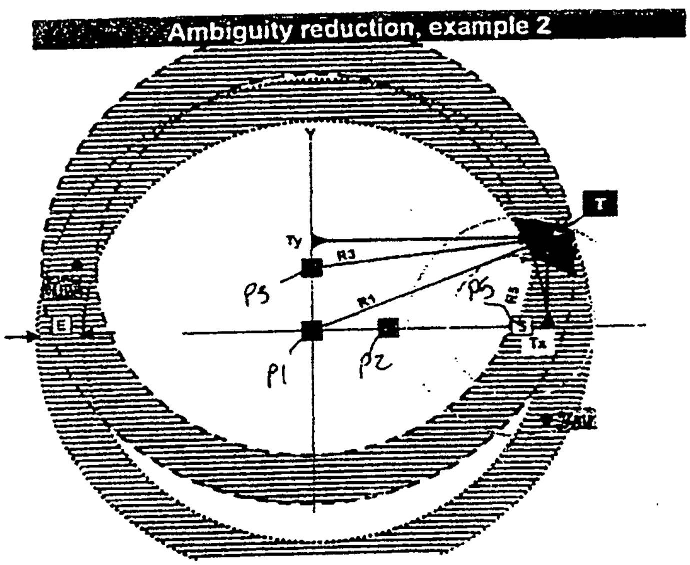


FIG. 11

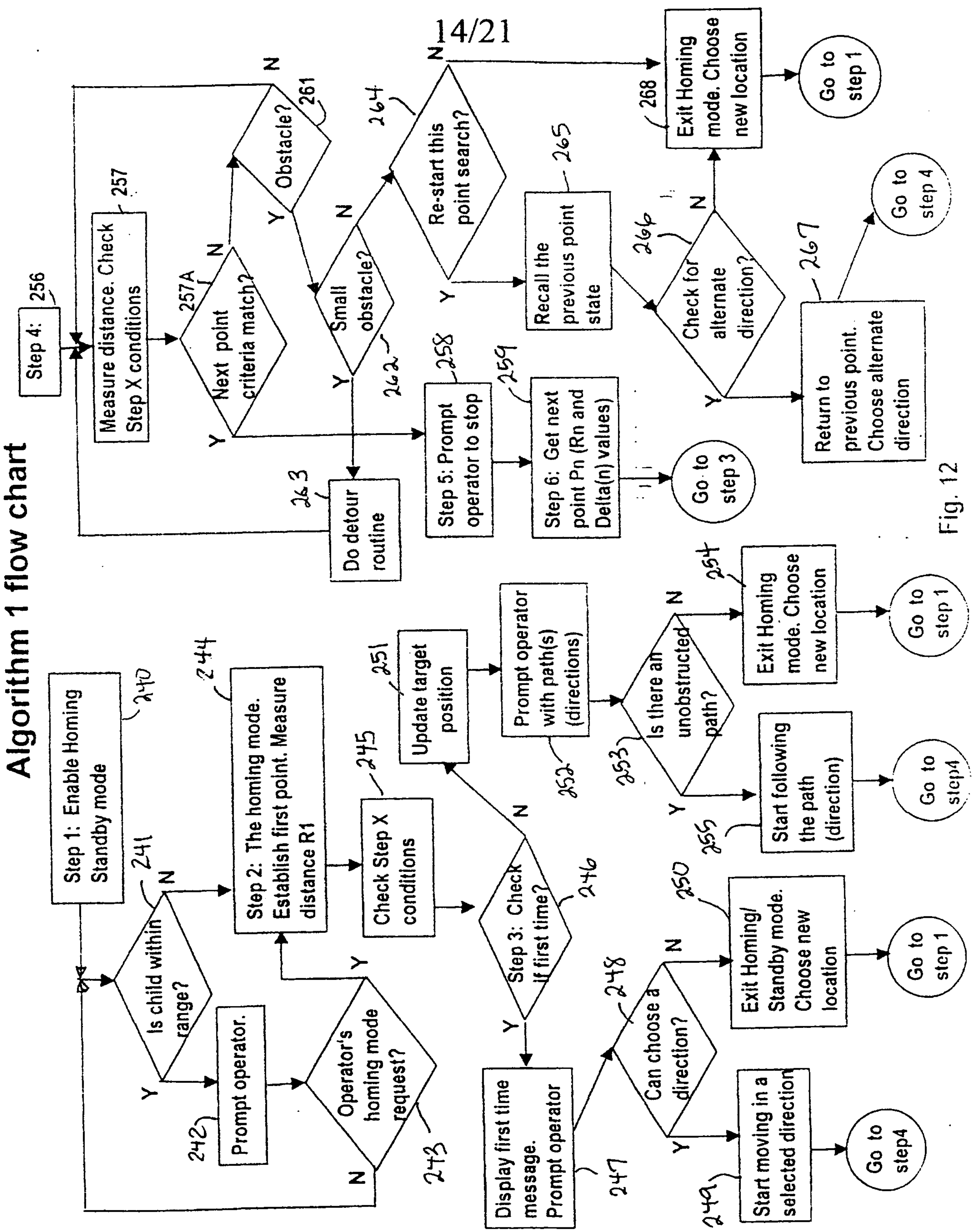
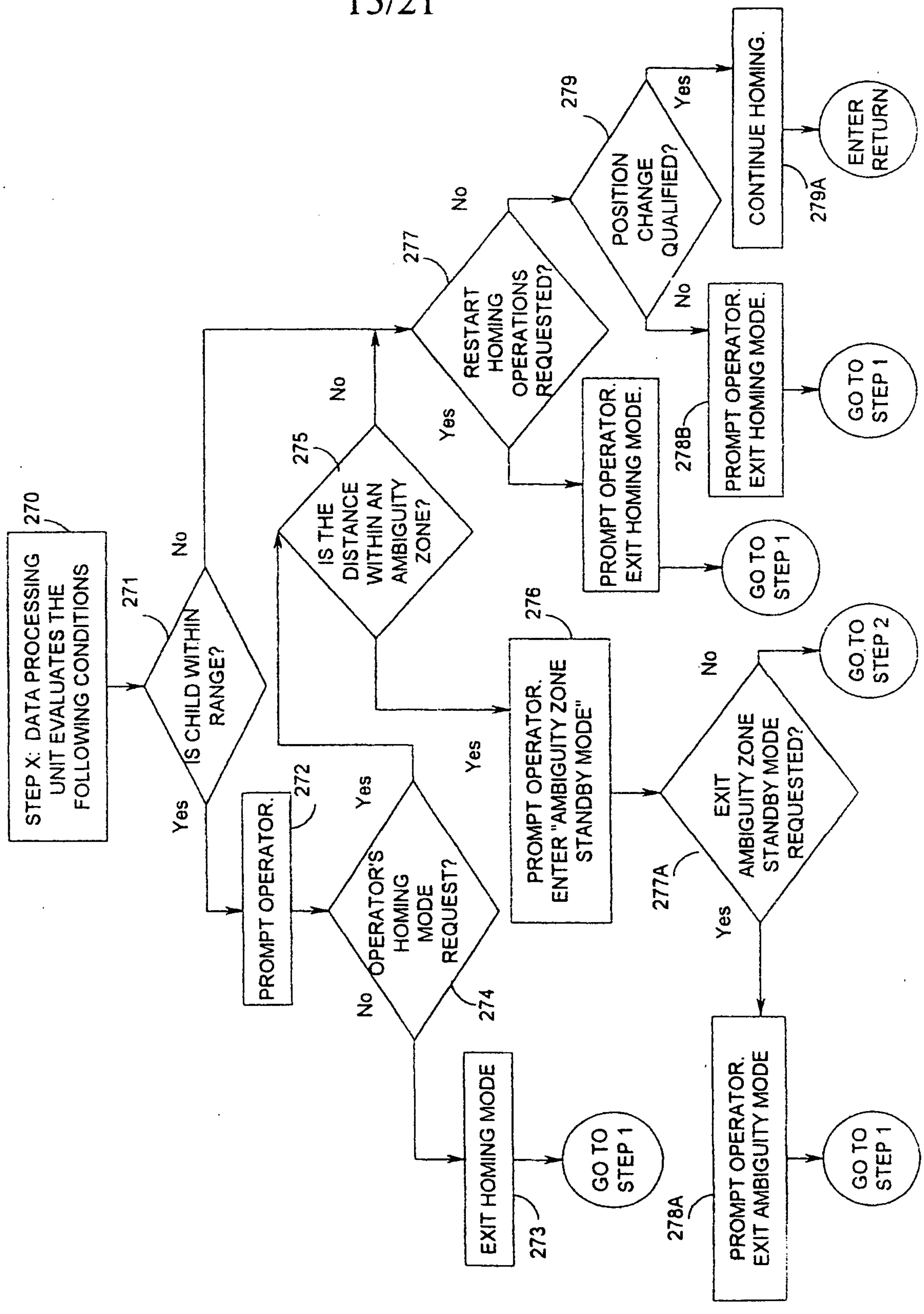

Algorithm 1 flow chart
Step 1: Enable Homing Standby mode
240
Is child within range?
241
N
Y
Prompt operator.
242
Operator's homing mode request?
243
Y
N
Step 2: The homing mode. Establish first point. Measure distance R1
244
Check Step X conditions
245
Step 3: Check if first time?
246
N
Y
Display first time message. Prompt operator
247
Can choose a direction?
248
N
Y
Exit Homing/ Standby mode. Choose new location
250
Go to step 1
Start moving in a selected direction
249
Go to step4
Update target position
251
Prompt operator with path(s) (directions)
252
Is there an unobstructed path?
253
N
Y
Exit Homing mode. Choose new location
254
Go to step 1
Start following the path (direction)
255
Go to step4
Step 4:
256
Measure distance. Check Step X conditions
257
Next point criteria match?
257A
N
Y
Obstacle?
261
N
Y
Small obstacle?
262
N
Y
Do detour routine
263
Step 5: Prompt operator to stop
258
Step 6: Get next point Pn (Rn and Delta(n) values)
259
Go to step 3
Re-start this point search?
264
N
Y
Recall the previous point state
265
Check for alternate direction?
266
N
Y
Exit Homing mode. Choose new location
268
Go to step 1
Return to previous point. Choose alternate direction
267
Go to step 4

Fig. 12

Fig. 13 ALGORITHM 1 FLOW CHART, CONTINUED



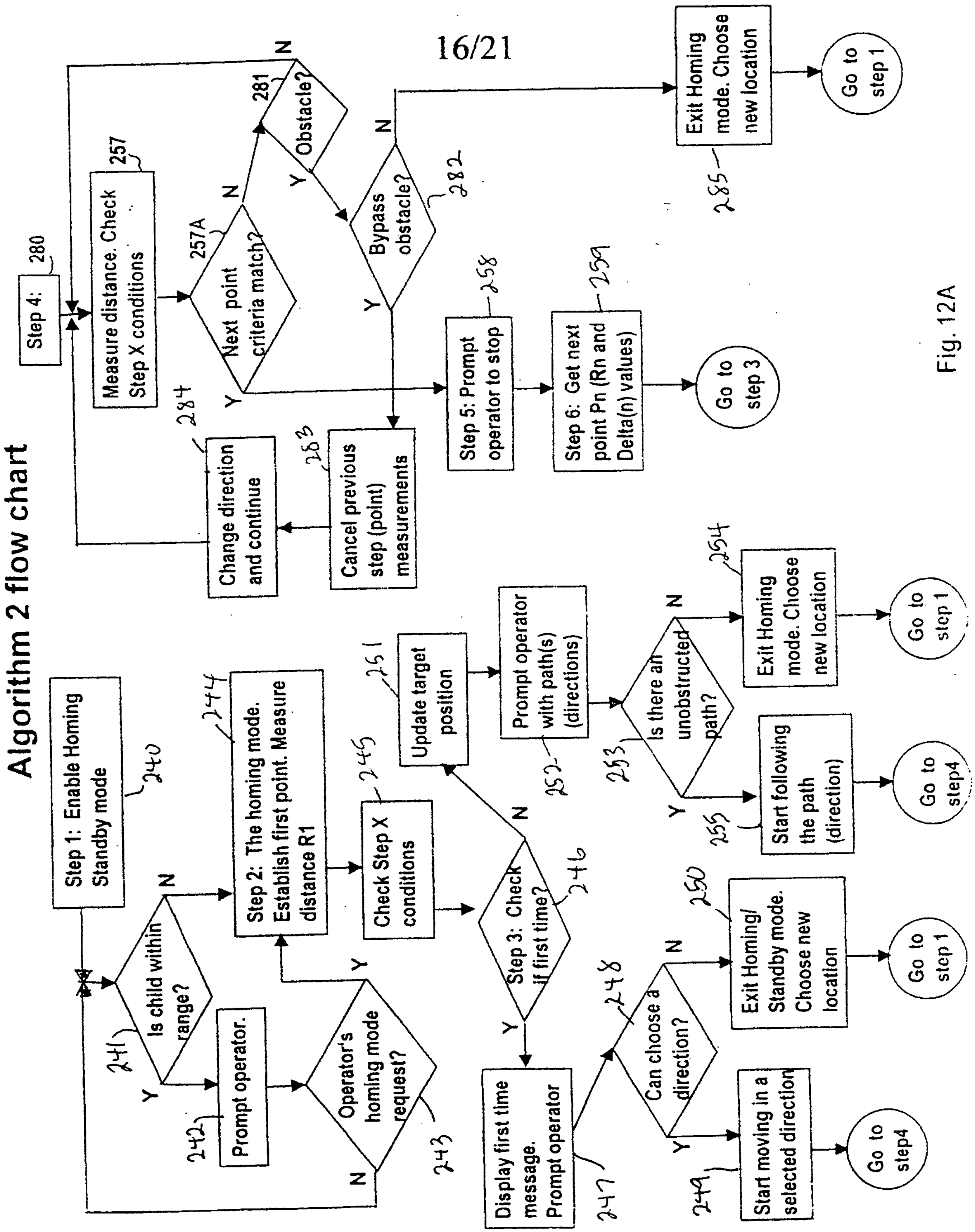
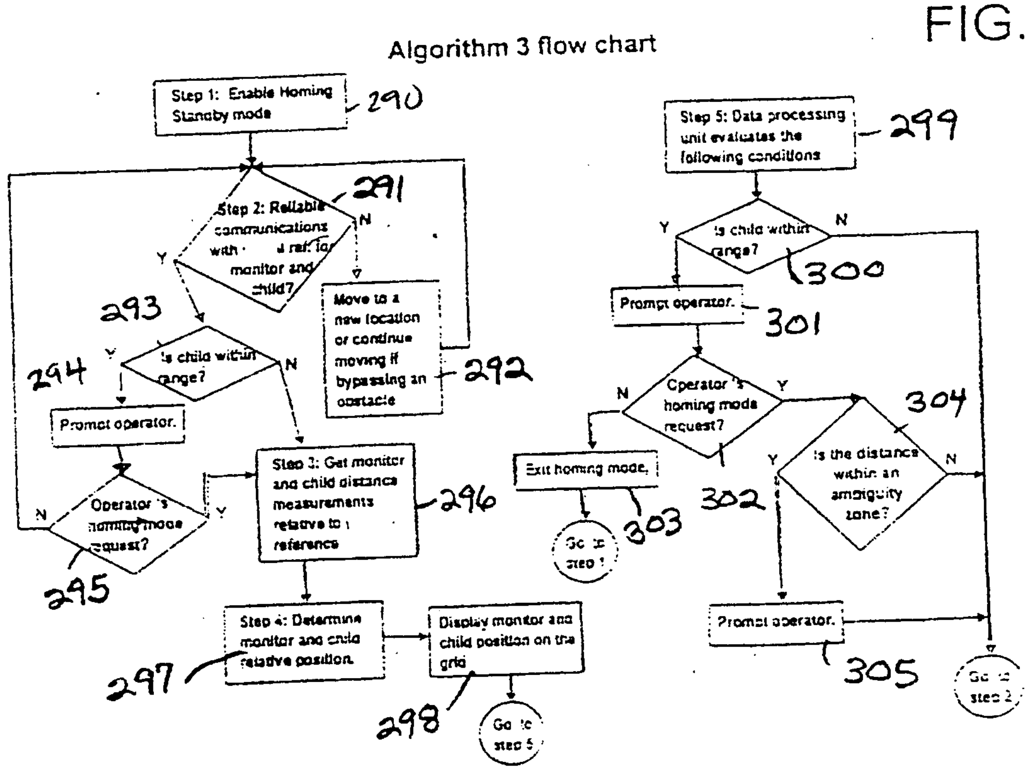

Algorithm 2 flow chart
Step 1: Enable Homing Standby mode
240
Is child within range?
241
N
Y
Prompt operator.
242
Operator's homing mode request?
243
Y
N
Step 2: The homing mode. Establish first point. Measure distance R1
244
Check Step X conditions
245
Step 3: Check if first time?
246
N
Y
Display first time message. Prompt operator
247
Can choose a direction?
248
N
Y
Exit Homing/ Standby mode. Choose new location
250
Go to step 1
Start moving in a selected direction
249
Go to step4
Update target position
251
Prompt operator with path(s) (directions)
252
Is there an unobstructed path?
253
N
Y
Exit Homing mode. Choose new location
254
Go to step 1
Start following the path (direction)
255
Go to step4
Step 4:
280
Measure distance. Check Step X conditions
257
Next point criteria match?
257A
N
Y
Obstacle?
281
N
Y
Bypass obstacle?
282
N
Y
Exit Homing mode. Choose new location
285
Go to step 1
Cancel previous step (point) measurements
283
Change direction and continue
284
Step 5: Prompt operator to stop
258
Step 6: Get next point Pn (Rn and Delta(n) values)
259
Go to step 3

Fig. 12A

FIG. 14


Algorithm 3 flow chart
Step 1: Enable Homing Standby mode
290
Step 2: Reliable communications with a ref. for monitor and child?
291
Move to a new location or continue moving if bypassing an obstacle
292
293
Is child within range?
294
Prompt operator.
Operator's homing mode request?
295
Step 3: Get monitor and child distance measurements relative to reference
296
Step 4: Determine monitor and child relative position.
297
Display monitor and child position on the grid
298
Go to step 5
Step 5: Data processing unit evaluates the following conditions
299
Is child within range?
300
Prompt operator.
301
Operator's homing mode request?
302
Exit homing mode.
303
Go to step 1
Is the distance within an ambiguity zone?
304
Prompt operator.
305
Go to step 2
Y
N

Algorithm 1 homing example

FIG. 15

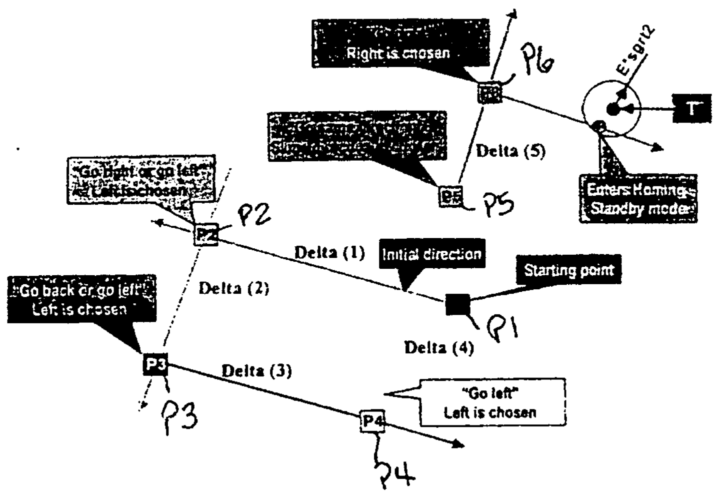
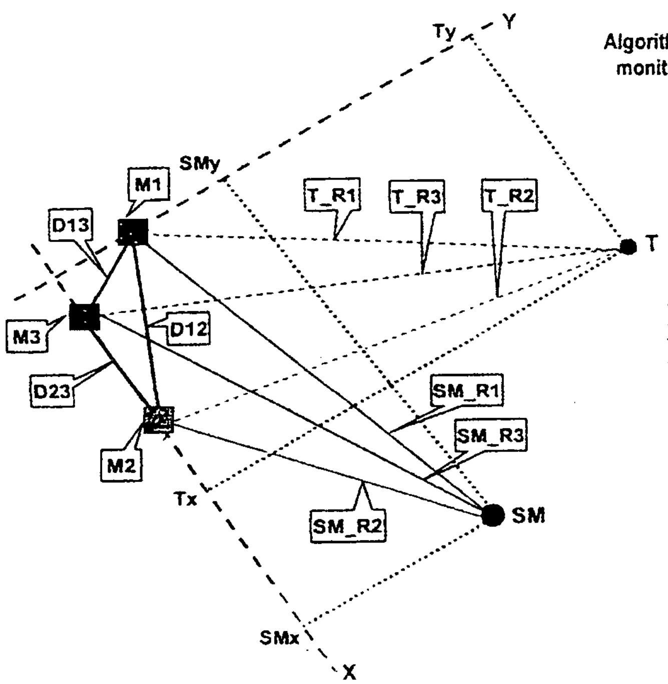


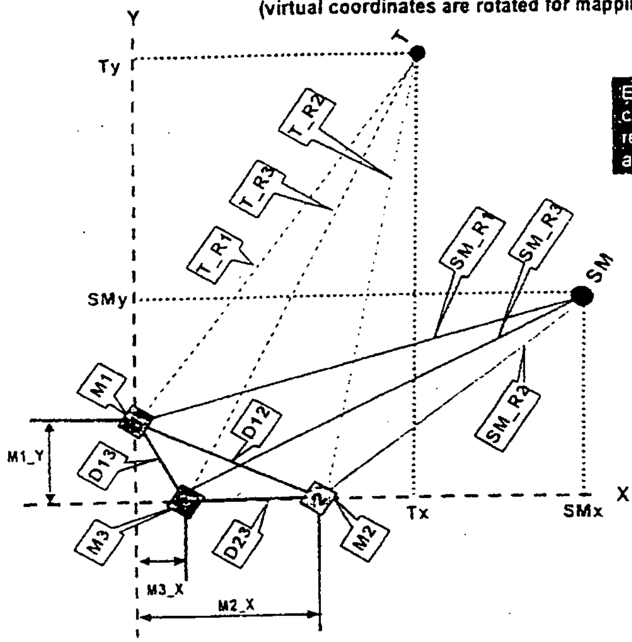
FIG. 16

Algorithm 3 homing. Three stationary monitors example - fixed reference



X, Y - virtual coordinates
SM - "searching monitor"
T - child target
Ty, Tx - target virtual coordinates
SMx, SMy - "Searching Monitor" virtual coordinates
DXX - distance between reference monitors
T_Rn - distance between reference monitors and Target
SM_Rn - distance between reference monitors and the "searching monitor"

Algorithm 3 homing. Three stationary monitors reference example, continued
(virtual coordinates are rotated for mapping into display grid)



Every position and virtual X, Y coordinates are rotated. However, relative positions between all monitors and child target is unchanged

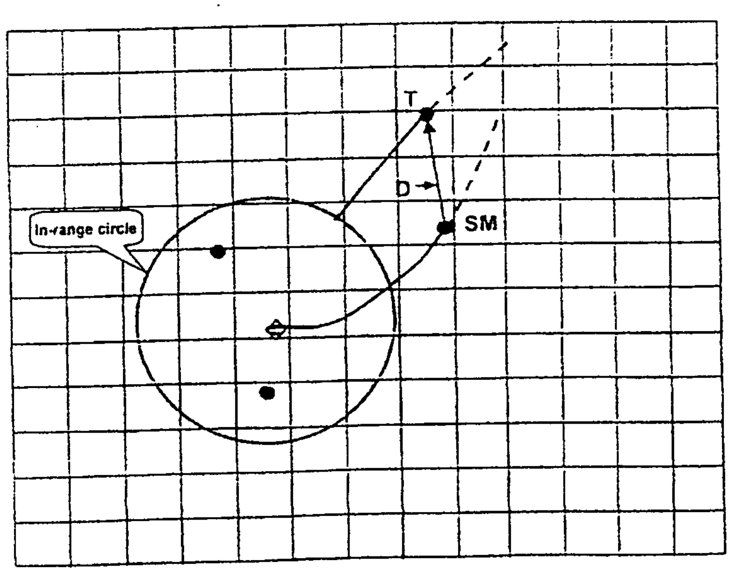
M1, M2, M3 - positions of three fixed reference monitors
Mn_Y, Mn_X - stationary reference virtual coordinates

M1 - M3 coordinates (M1_Y, M3_X and M2_X values) are calculated from D12, D13 and D23 distances

Ty, Tx are calculated from T_Rn distances and M1 - M3 coordinates
SMy, SMx are calculated from SM_Rn distances and M1 - M3 coordinates

FIG. 17

Algorithm 3 homing. Three stationary monitors reference example, continued
(display grid)



Scale:

X

X (in meters or feet).
X value (resolution) - may be set automatically or by operator

Other child

SM initial position

Target trace

Search trace

D - SM to target distance

Stationary reference monitors optionally are not displayed.
However, in range circle is displayed

FIG. 18

Algorithm 3 homing. Three moving monitors reference example, (display grid)

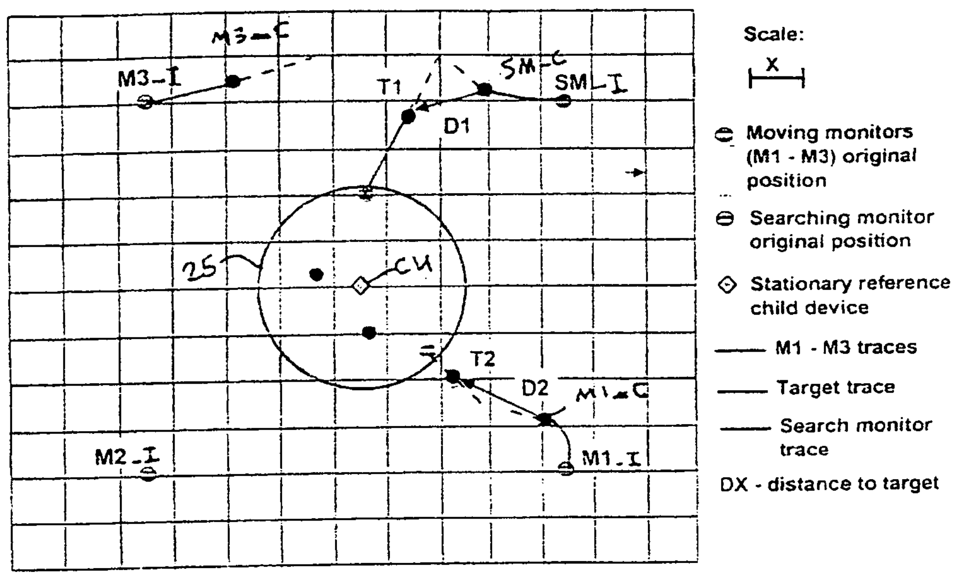


FIG. 19

Algorithm 2 homing. Three stationary child devices reference example (virtual coordinates are rotated)

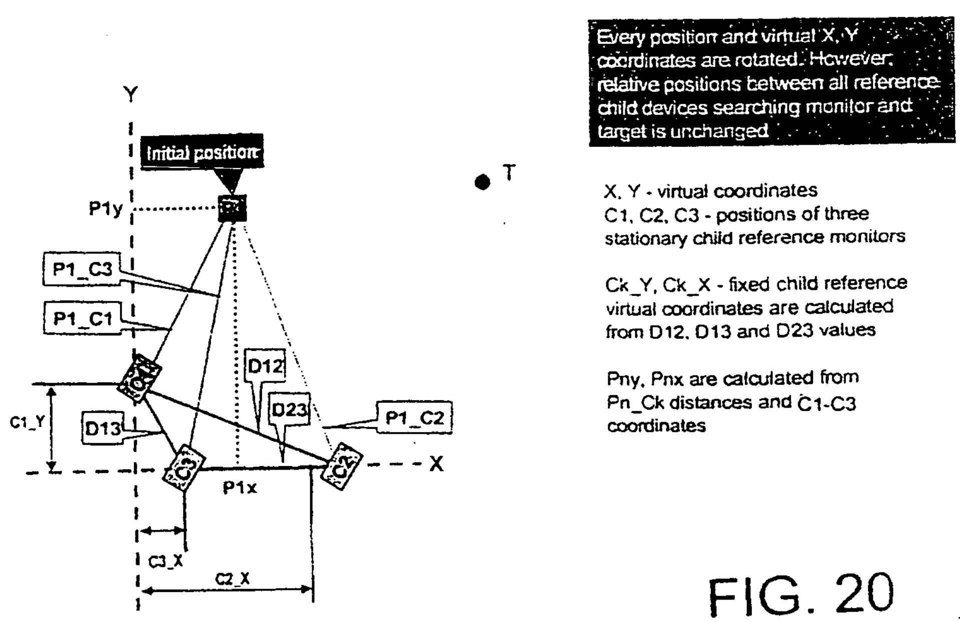


FIG. 20

Algorithm 2 homing. Three stationary child devices reference example, continued

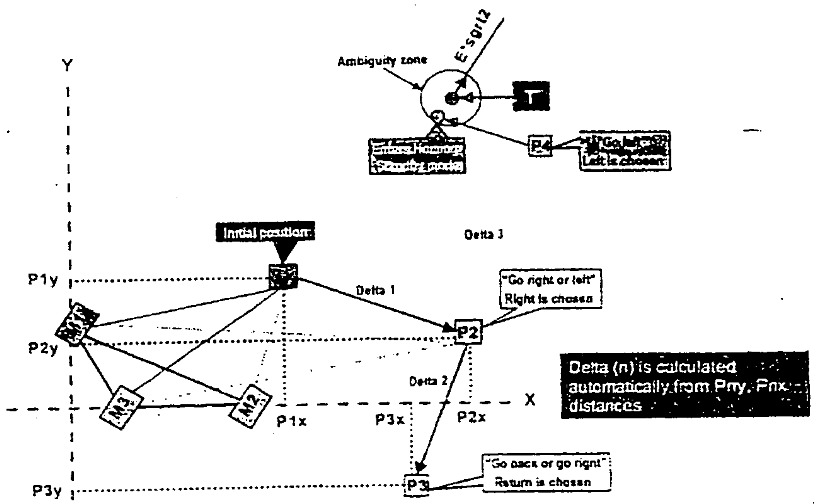


FIG. 21

Algorithm 2 homing. Three stationary child devices reference example, continued
(obstacle avoidance/bypassing)

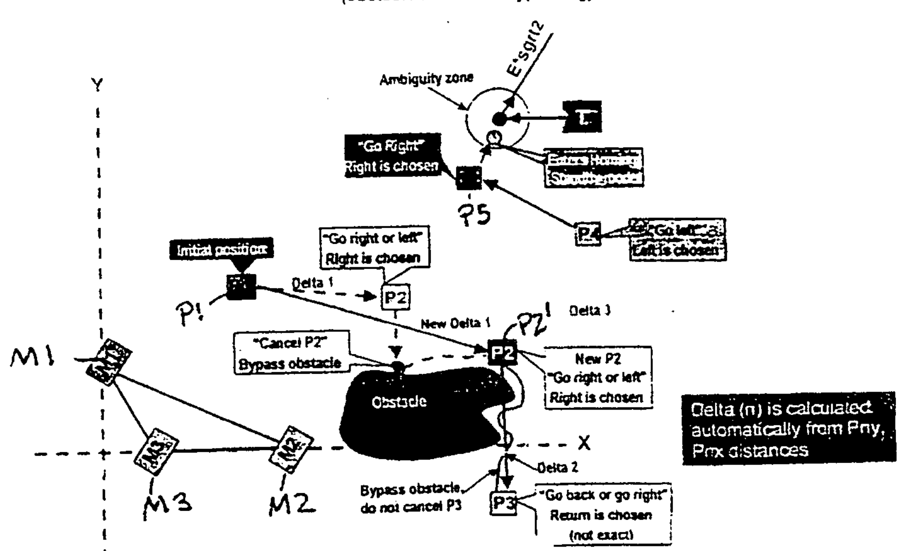
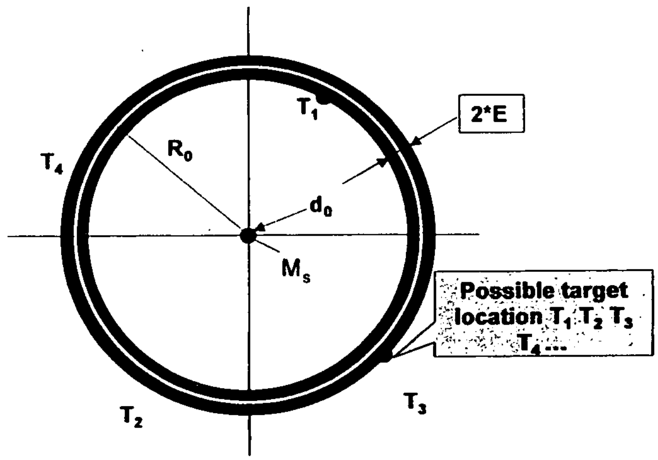
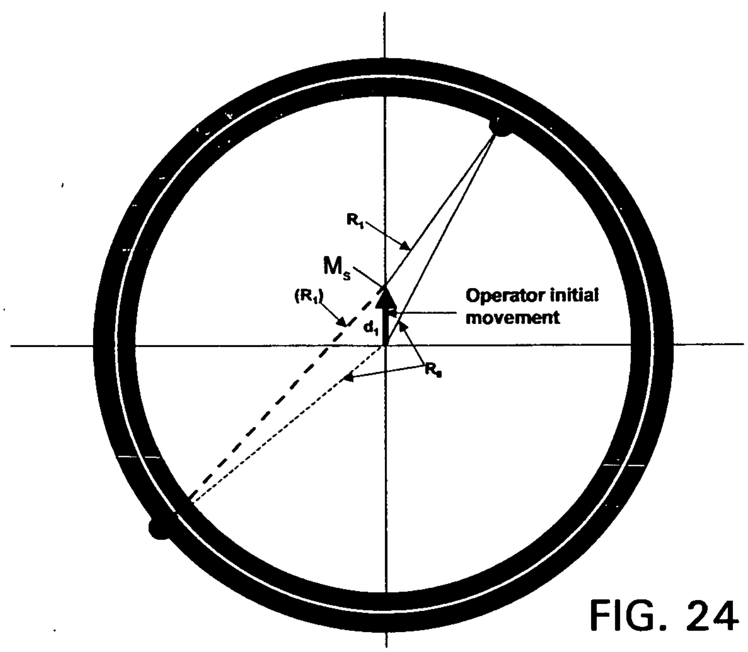


FIG. 22



T_1
2*E
T_4
R_0
d_0
M_s
Possible target location T_1 T_2 T_3 T_4...
T_2
T_3

FIG. 23



R_1
M_s
(R_1)
d_1
Operator initial movement
R_0

FIG. 24

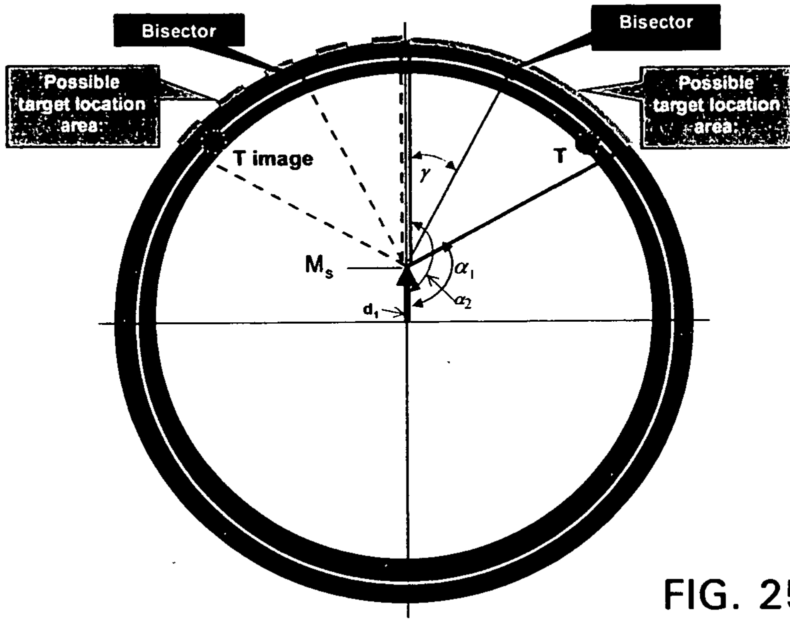

Bisector
Bisector
Possible target location area:
Possible target location area:
T image
T
γ
M s
α 1
α 2
d 1

FIG. 25

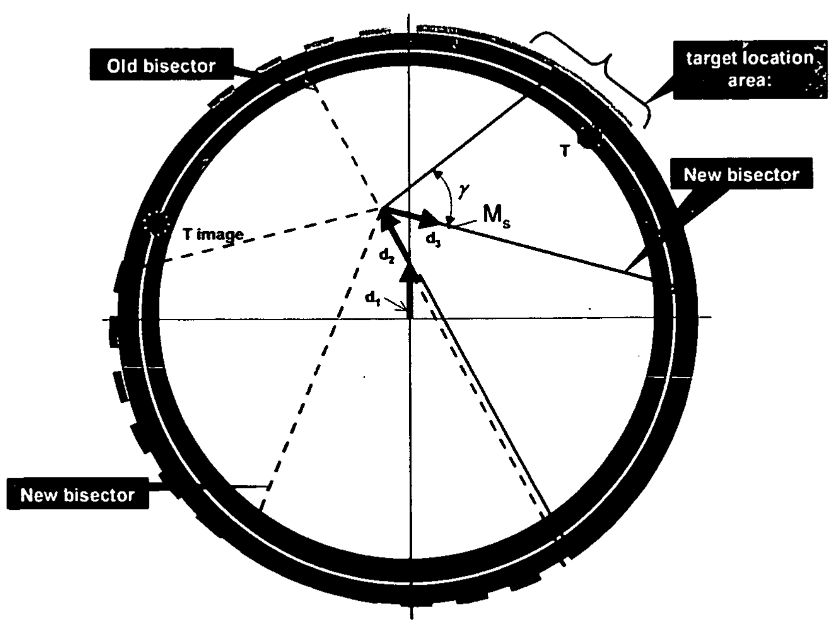

Old bisector
target location area:
T
New bisector
γ
M s
T image
d 2
d 3
d 1
New bisector

FIG. 26

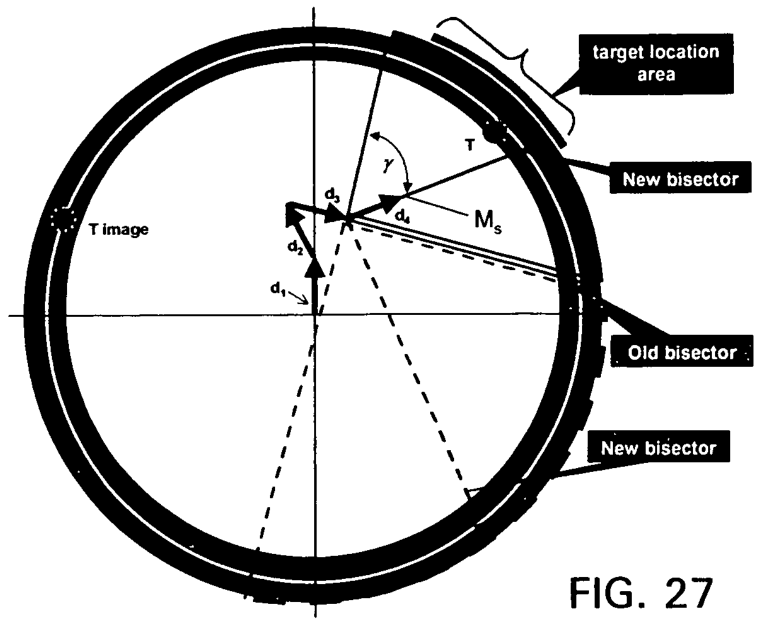

target location area
New bisector
T
γ
M_s
d_3
d_4
T image
d_2
d_1
Old bisector
New bisector

FIG. 27

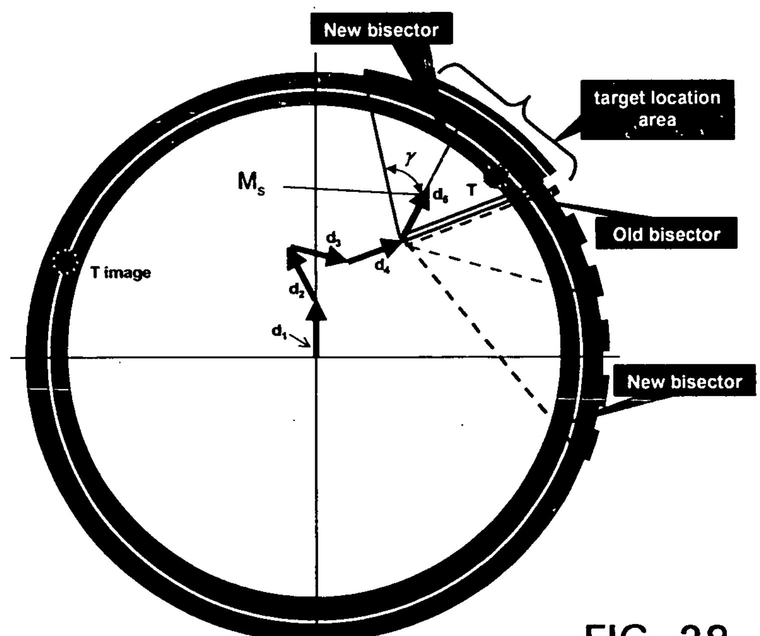

New bisector
target location area
γ
M_s
d_5
T
Old bisector
d_3
d_4
T image
d_2
d_1
New bisector

FIG. 28

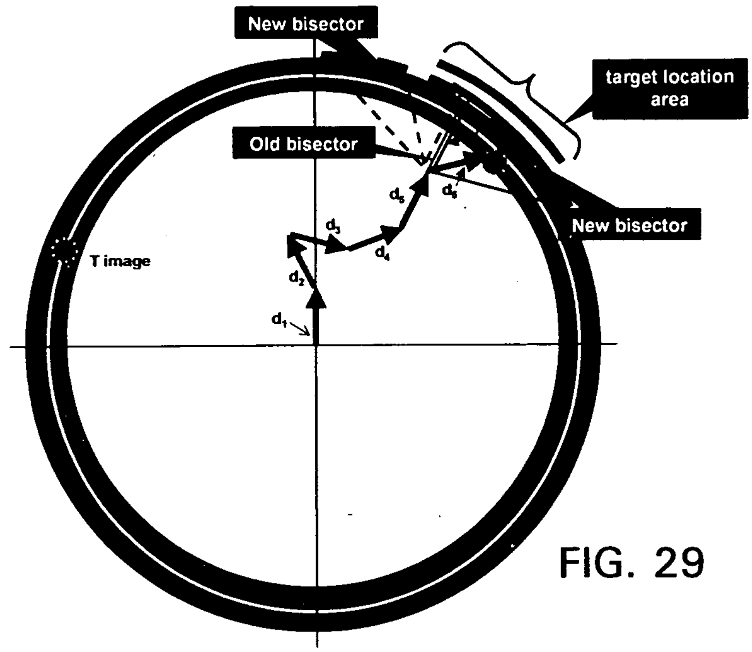

New bisector
target location area
Old bisector
New bisector
d_1
d_2
d_3
d_4
d_5
d_6
T image

FIG. 29

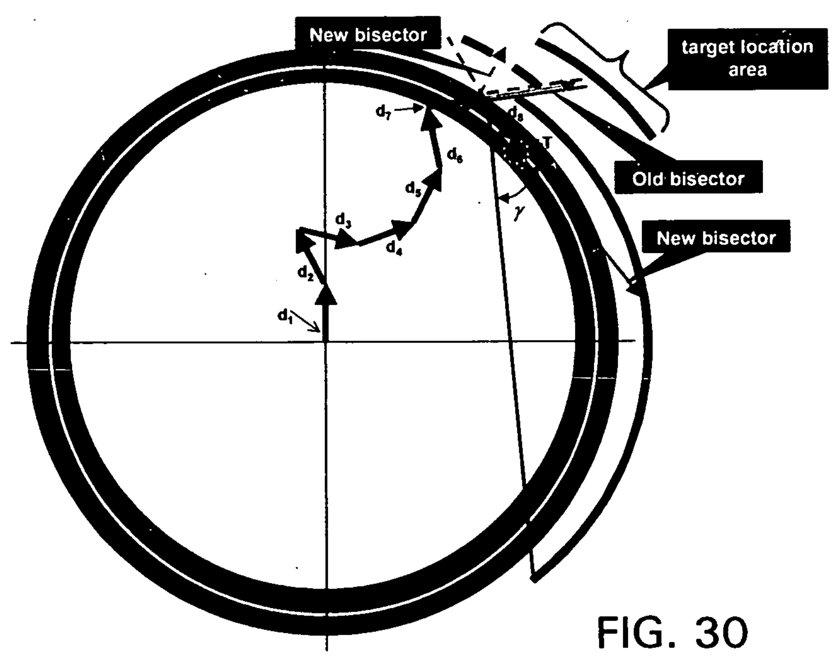
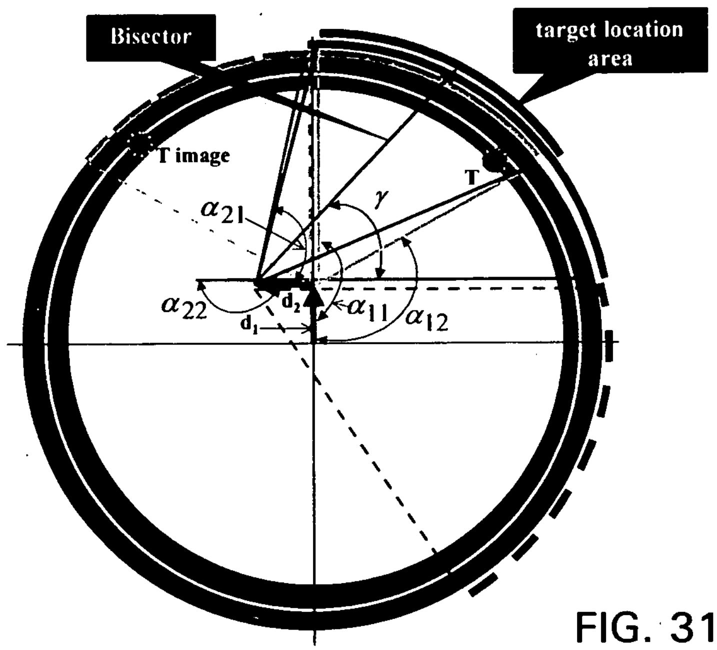
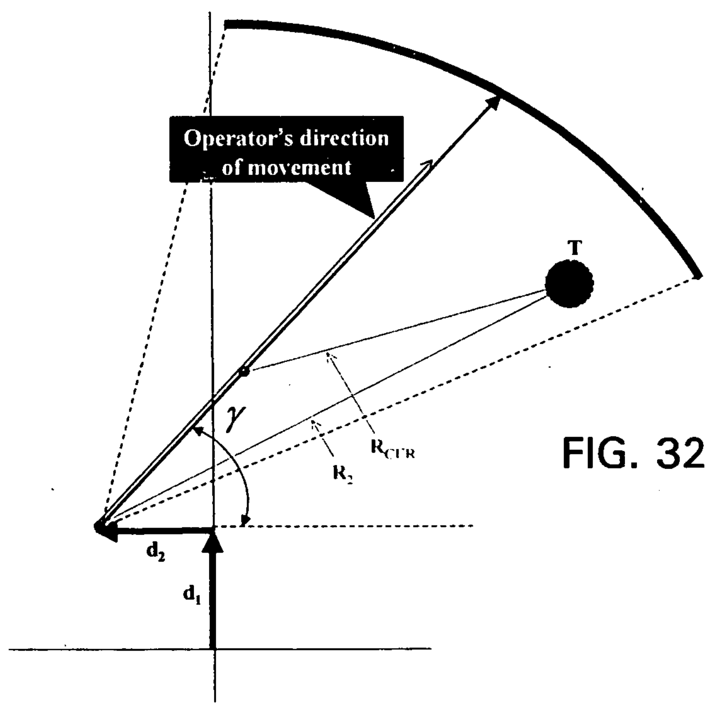

New bisector
target location area
Old bisector
New bisector
d_1
d_2
d_3
d_4
d_5
d_6
d_7
d_8
T
γ

FIG. 30



Bisector
target location area
T image
T
α_{21}
γ
α_{22}
d_2
d_1
α_{11}
α_{12}

FIG. 31



Operator's direction of movement
T
γ
R_{CUR}
R_2
d_2
d_1

FIG. 32

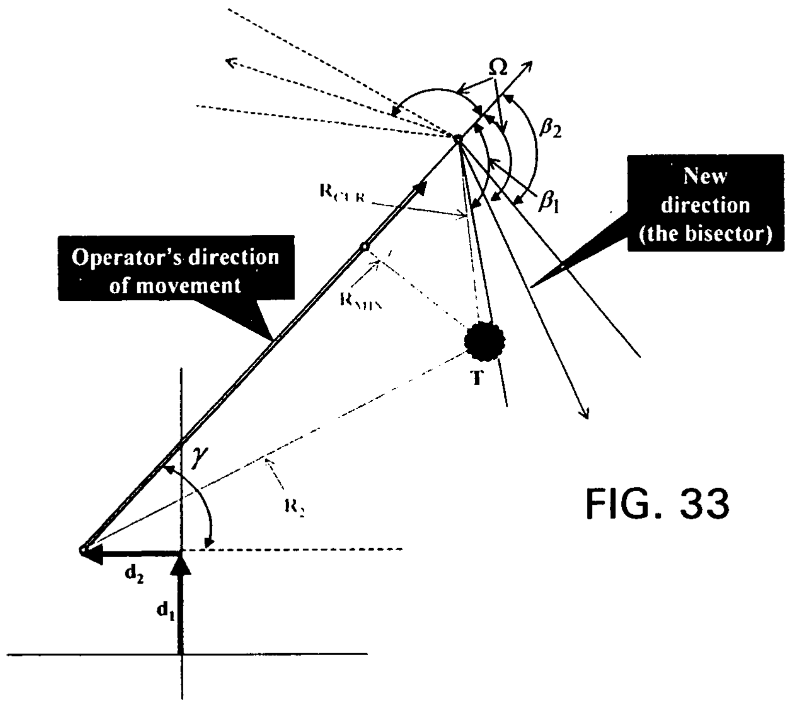

Ω
β_2
β_1
R_{CUR}
New direction (the bisector)
Operator's direction of movement
R_{MIN}
T
γ
R_2
d_2
d_1

FIG. 33

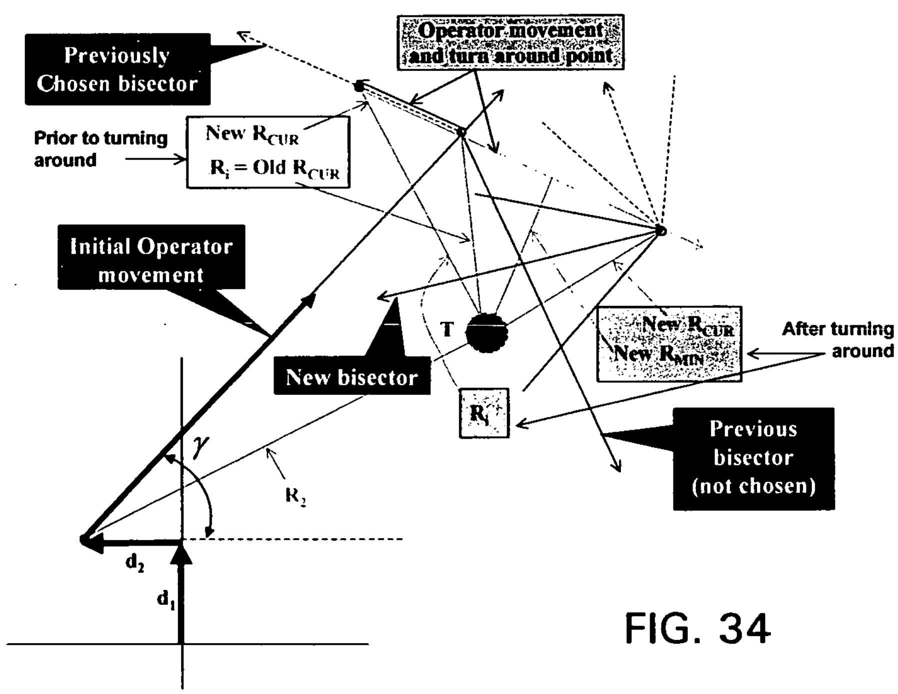

Previously Chosen bisector
Operator movement and turn around point
Prior to turning around
New R_{CUR}
R_i = Old R_{CUR}
Initial Operator movement
T
New bisector
New R_{CUR}
New R_{MIN}
After turning around
R_i
Previous bisector (not chosen)
γ
R_2
d_2
d_1

FIG. 34

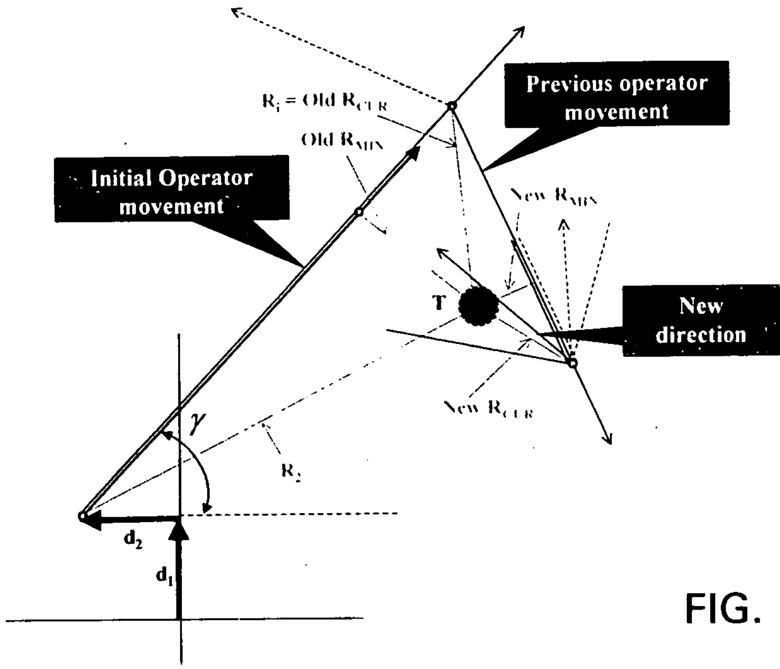

Previous operator movement
Initial Operator movement
New direction
T
γ
d_2
d_1

FIG. 35

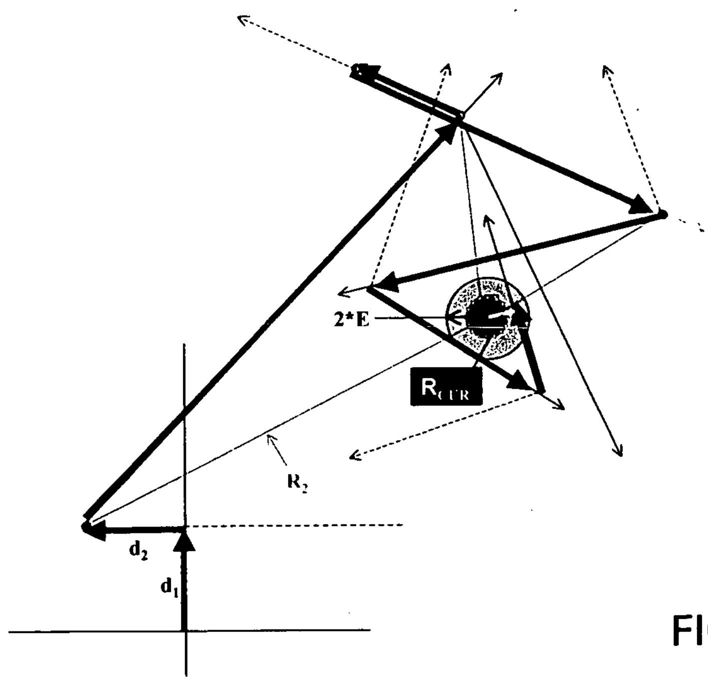

2*E
R_2
d_2
d_1

FIG. 36

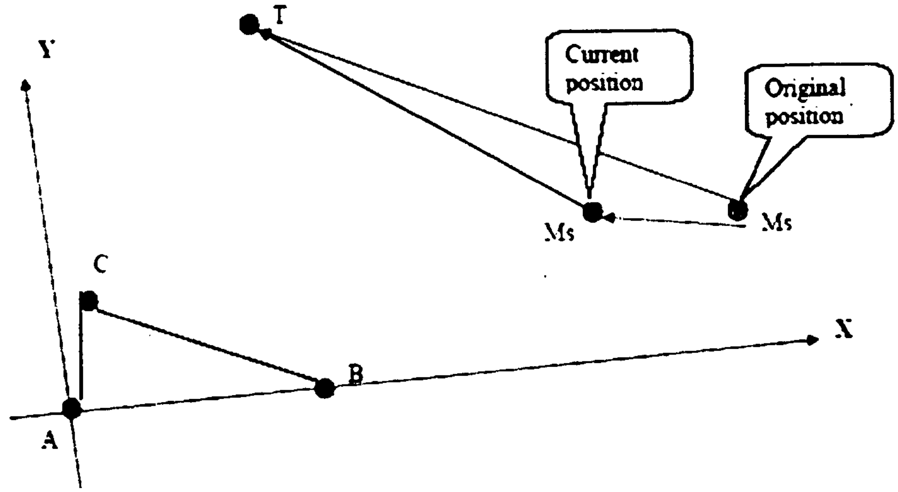


FIG. 38A

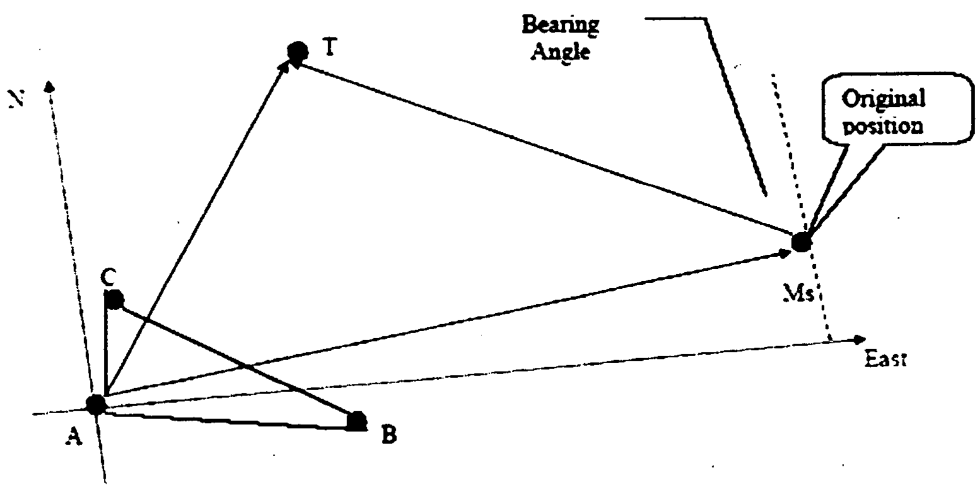


FIG. 38B

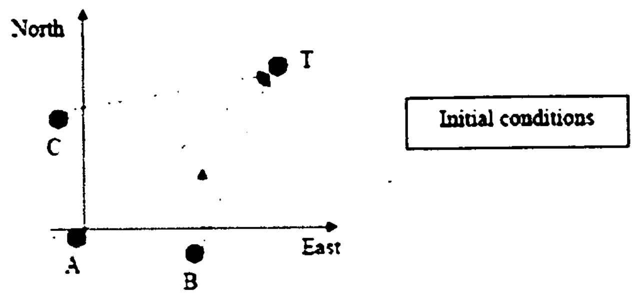


FIG. 39A

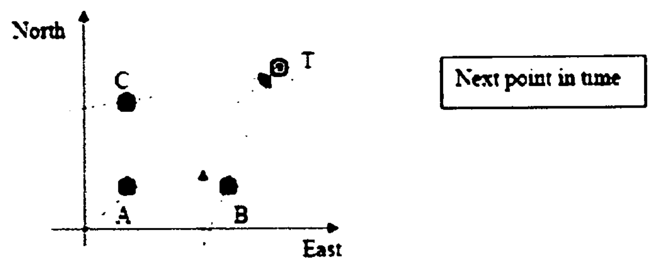


FIG. 39B

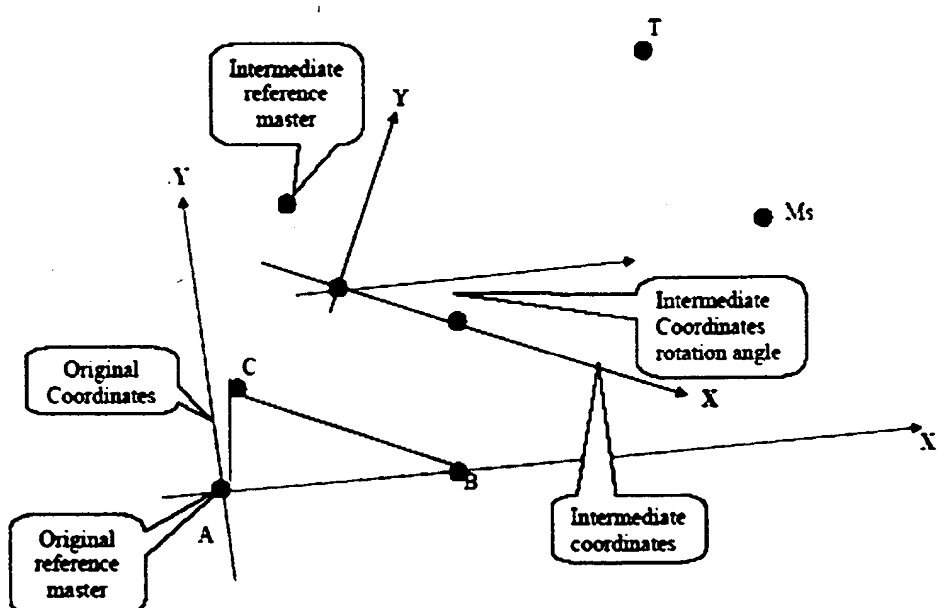
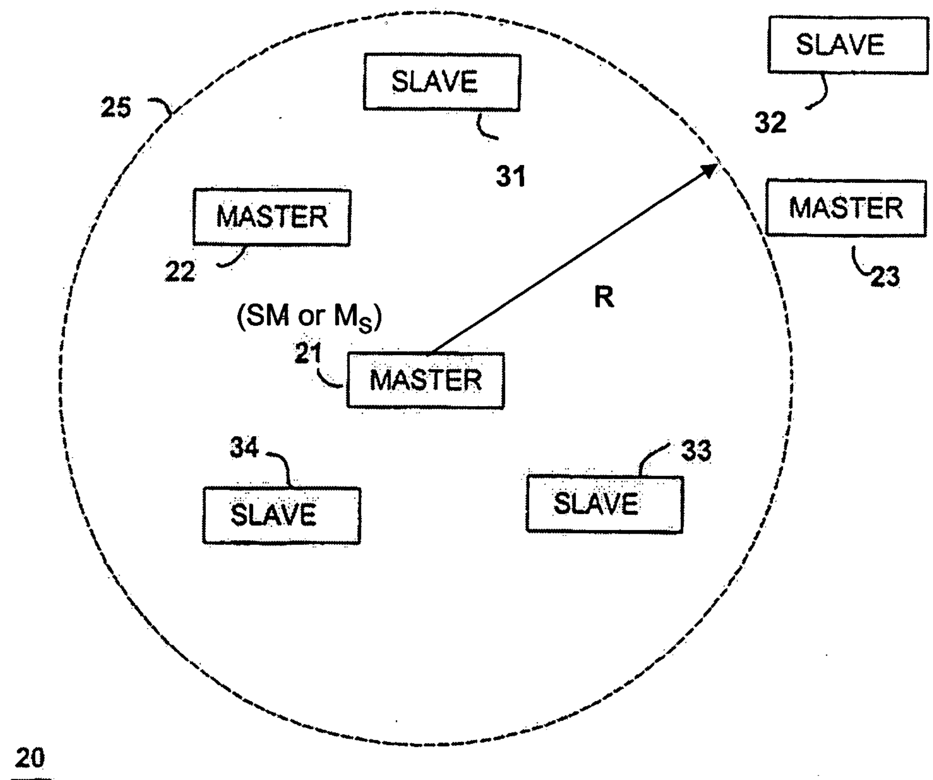


FIG. 40

ABSTRACT

[0253] A wireless system (20) and method for determining the location of a fixed or mobile target (31, 32, 33...) configured to have a transponder (31, 64) on the target (31, 32, 33...), a transceiver (21, 44) monitoring the target location, communicating between the transponder (31, 64) and transceiver (21, 44), and a processor (40) for finding the target by virtual triangulation based on values of received position information. The processor (40) is configured to determine virtual triangulation based on successive values of the position information using at least three points (P_1, P_2 and P_3) of the transponder (31) respective of the transceiver (21). The present invention discloses methods for finding with virtual triangulation by: (a) finding with virtual triangulation by generating position information in real-time, in the case of (i) stationary and moving target, and or (ii) in the case of the presence of obstacles; (b) finding with virtual triangulation relating to the average speed of the motion of operator; and or (c) finding with simplified virtual triangulation.

FIG. 1


SLAVE
SLAVE
25
32
31
MASTER
MASTER
22
23
R
(SM or M_S)
21
MASTER
34
33
SLAVE
SLAVE
20

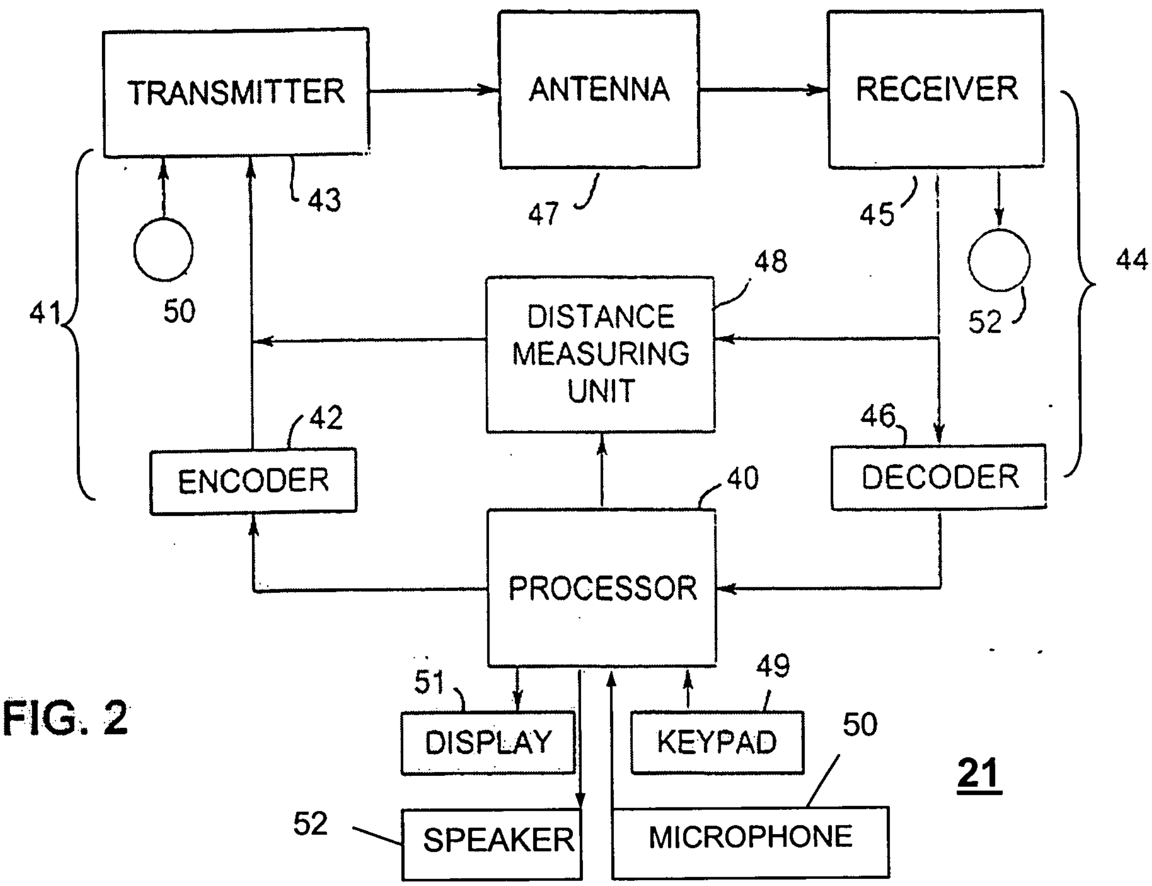

TRANSMITTER
ANTENNA
RECEIVER
43
47
45
50
52
44
41
48
DISTANCE MEASURING UNIT
42
46
ENCODER
DECODER
40
PROCESSOR
51
49
DISPLAY
KEYPAD
50
52
SPEAKER
MICROPHONE
21

FIG. 2

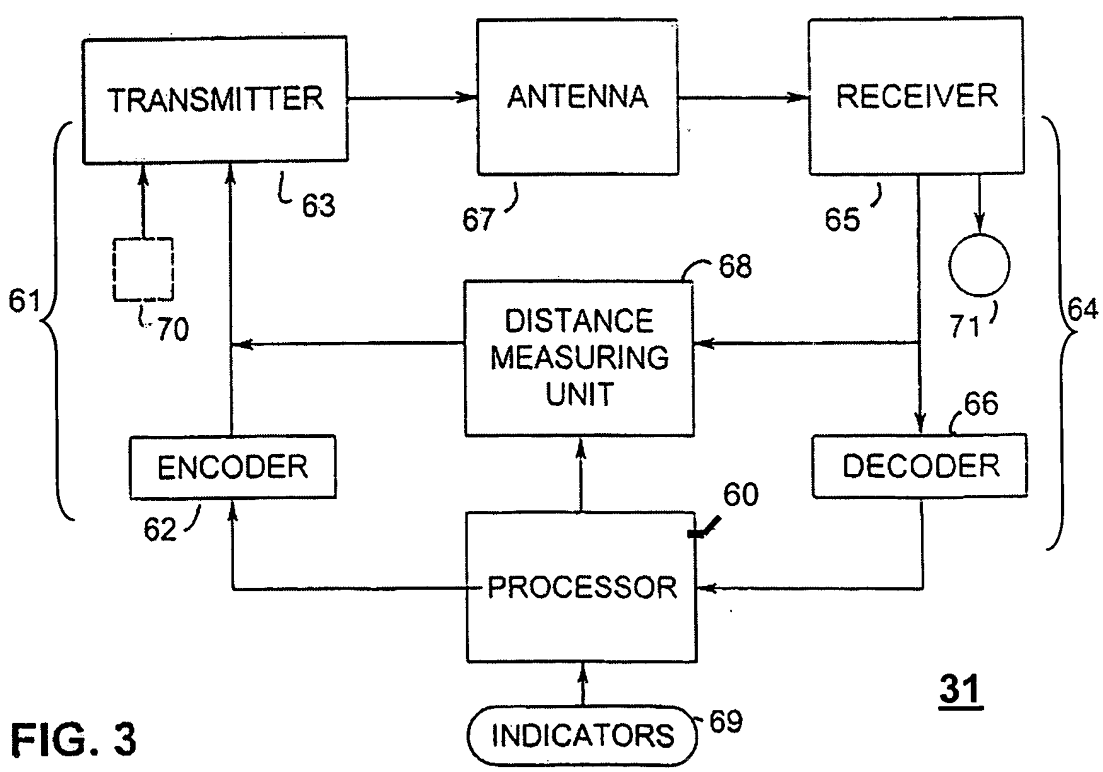

TRANSMITTER
ANTENNA
RECEIVER
63
67
65
68
70
71
61
64
DISTANCE MEASURING UNIT
66
ENCODER
DECODER
62
60
PROCESSOR
INDICATORS
69
31

FIG. 3

FIG. 3A

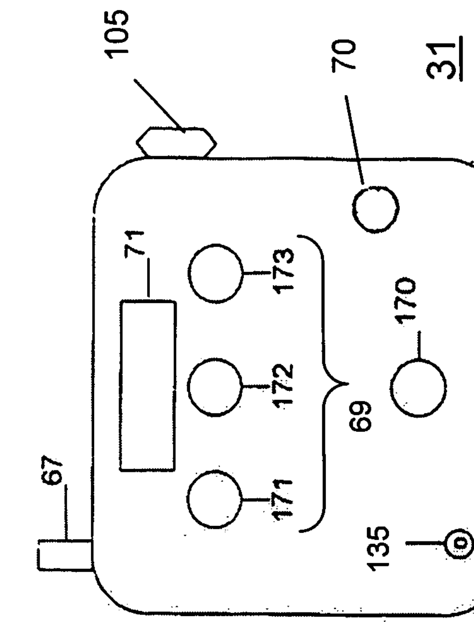
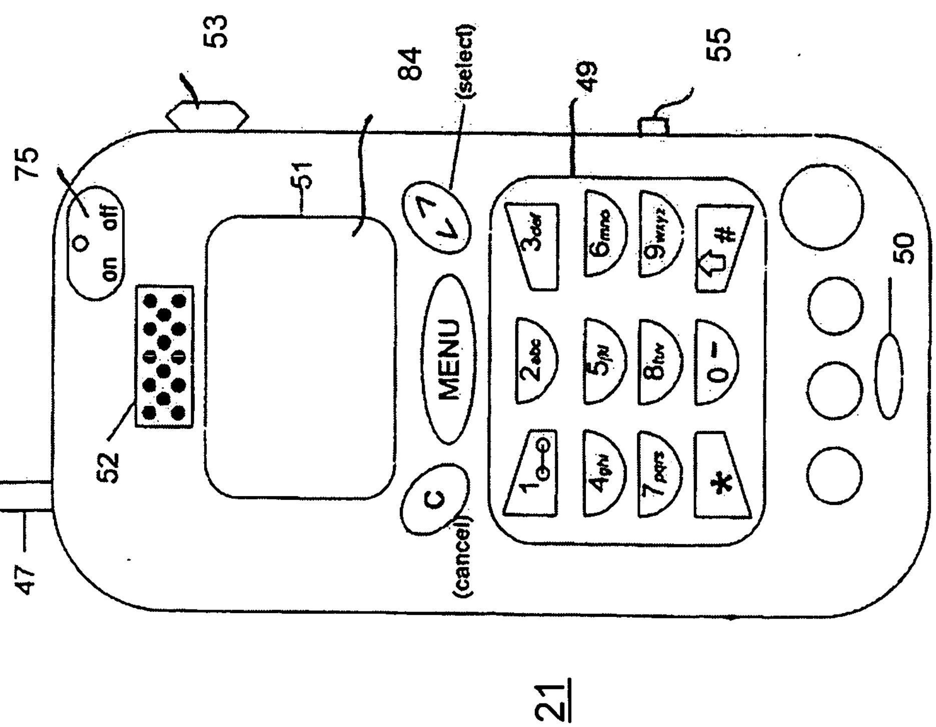

105
70
31
71
173
172
171
170
69
67
135

FIG. 2A


75
on off
53
84
(select)
49
55
51
MENU
C
(cancel)
52
50
47
21

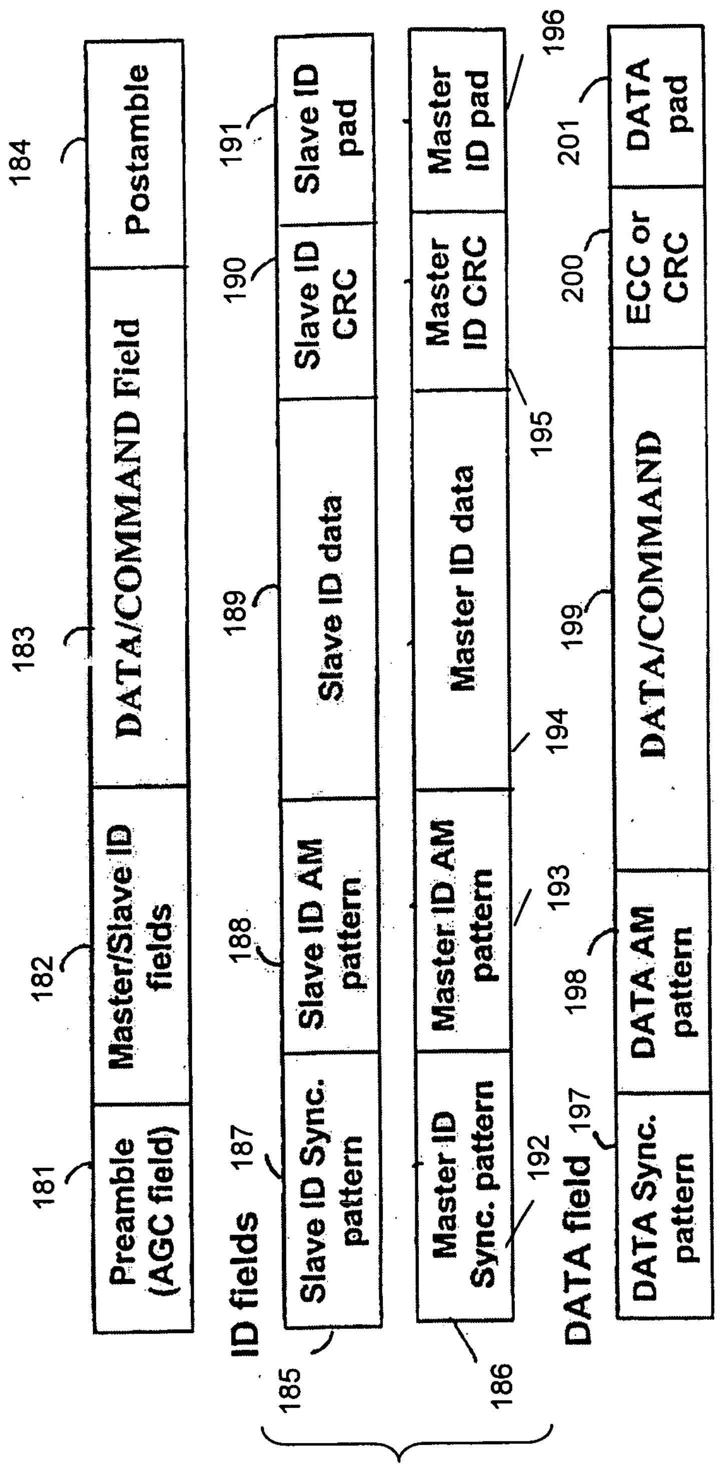


FIG. 3B

FIG. 3C

FIG. 3D

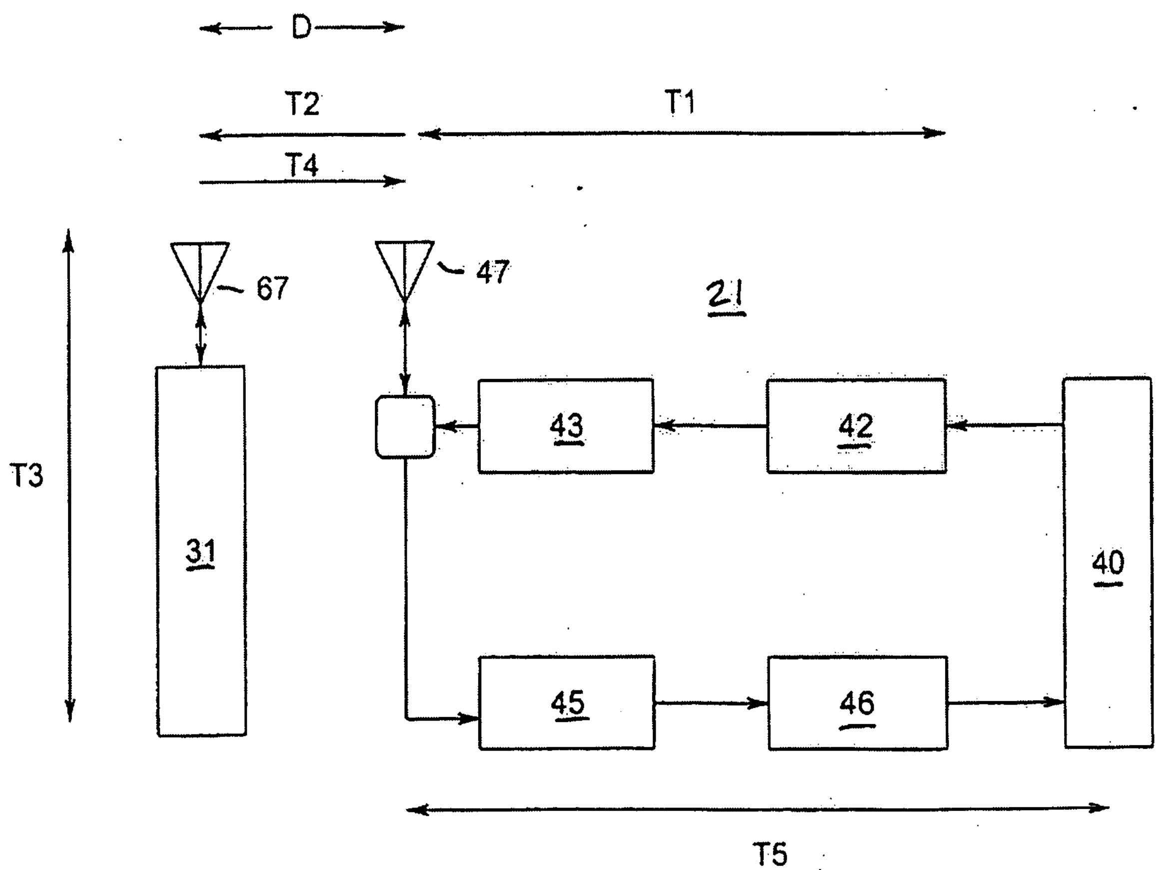


FIG. 4

FIG. 4A

DISTANCE/TIME MEASUREMENT SEQUENCE - OPTION 1

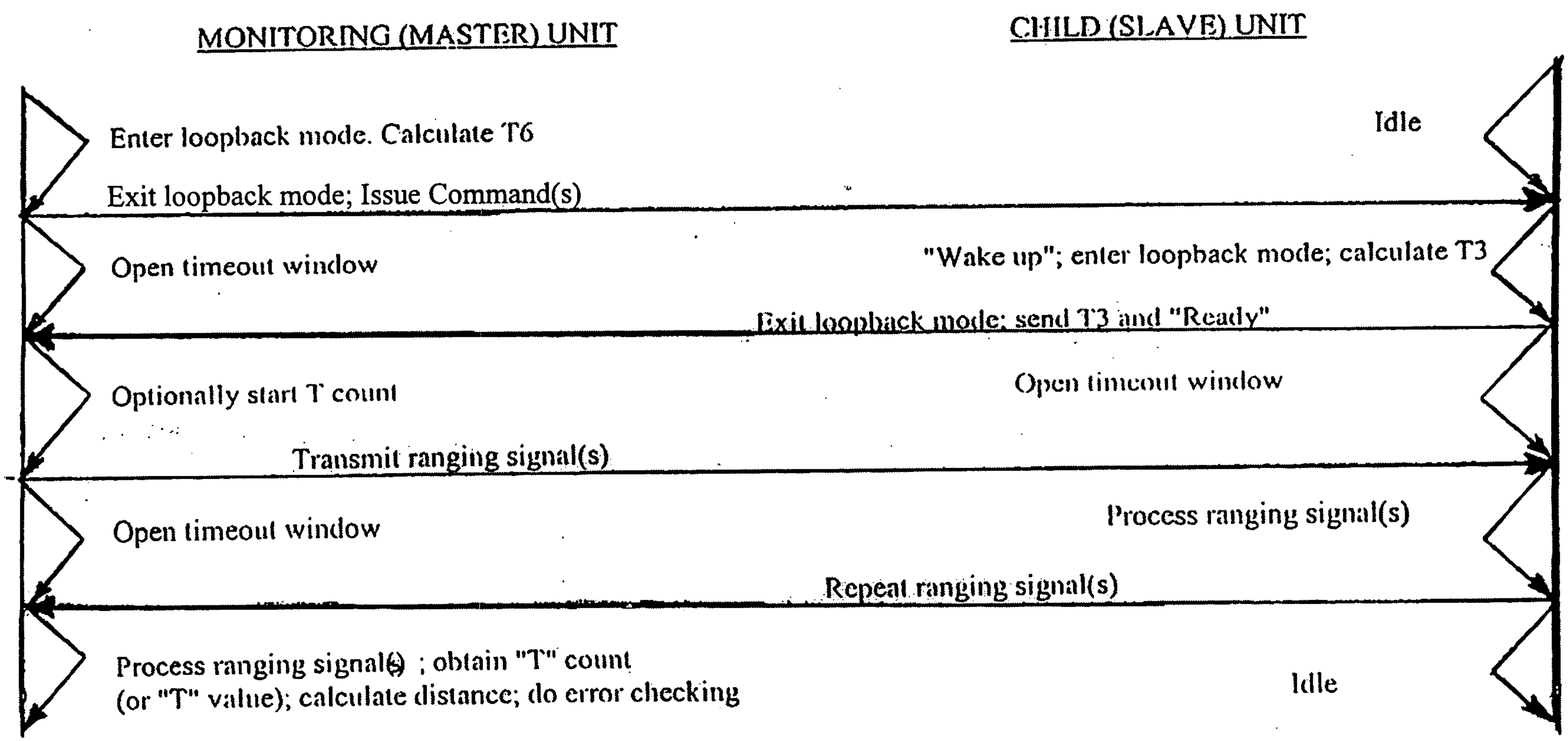


FIG. 4B

DISTANCE/TIME MEASUREMENT SEQUENCE - OPTION 2

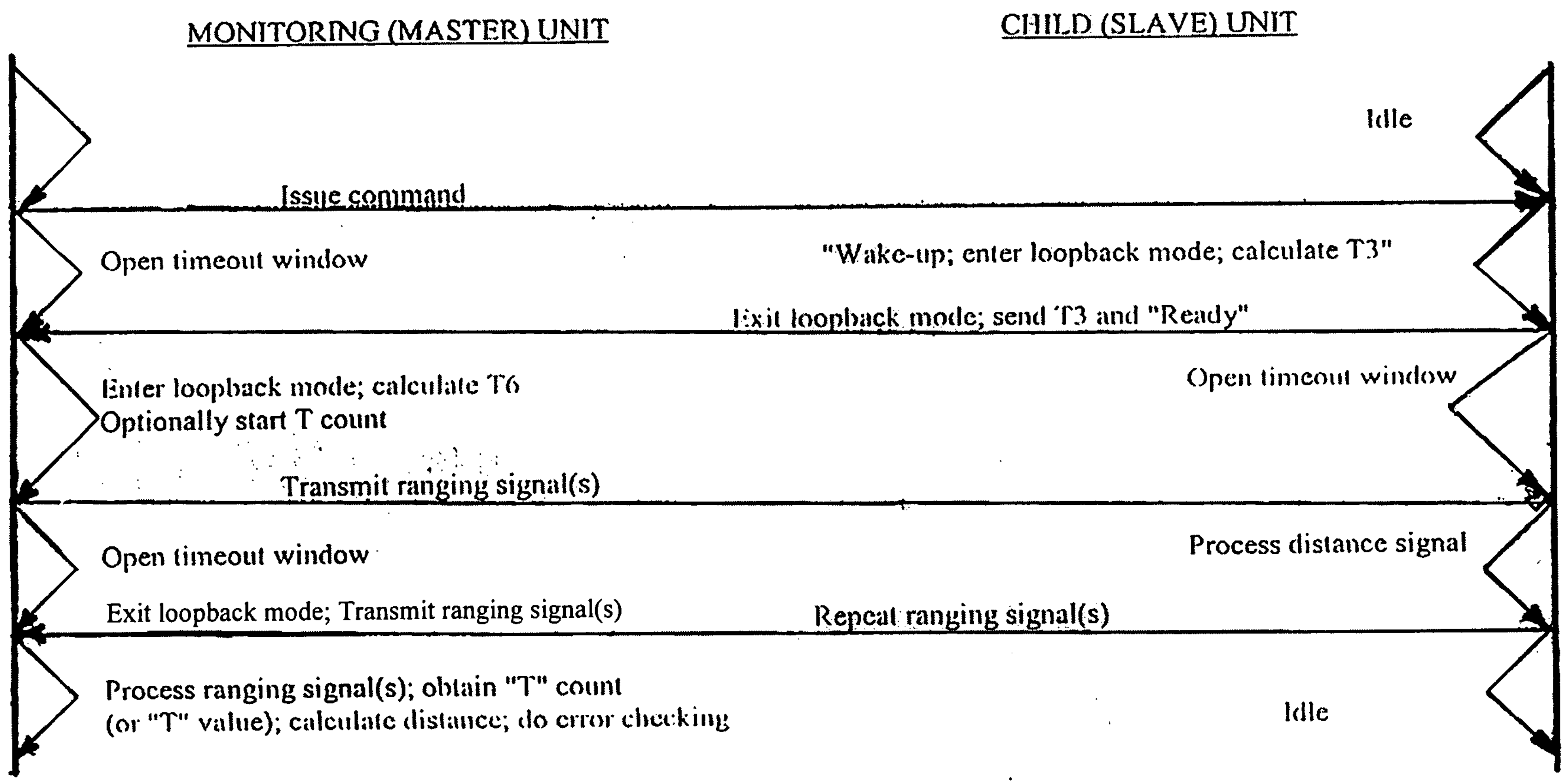


FIG. 5

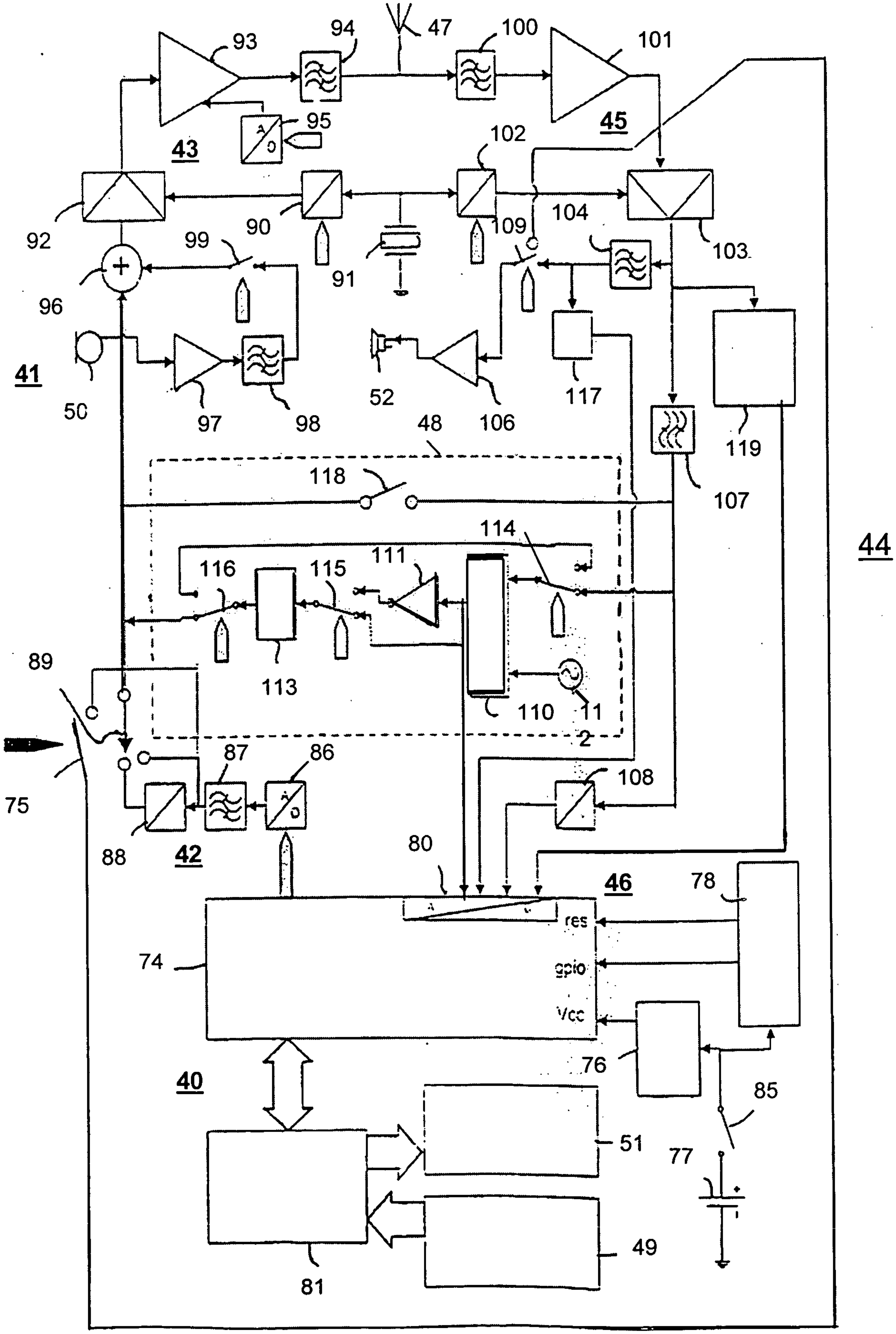
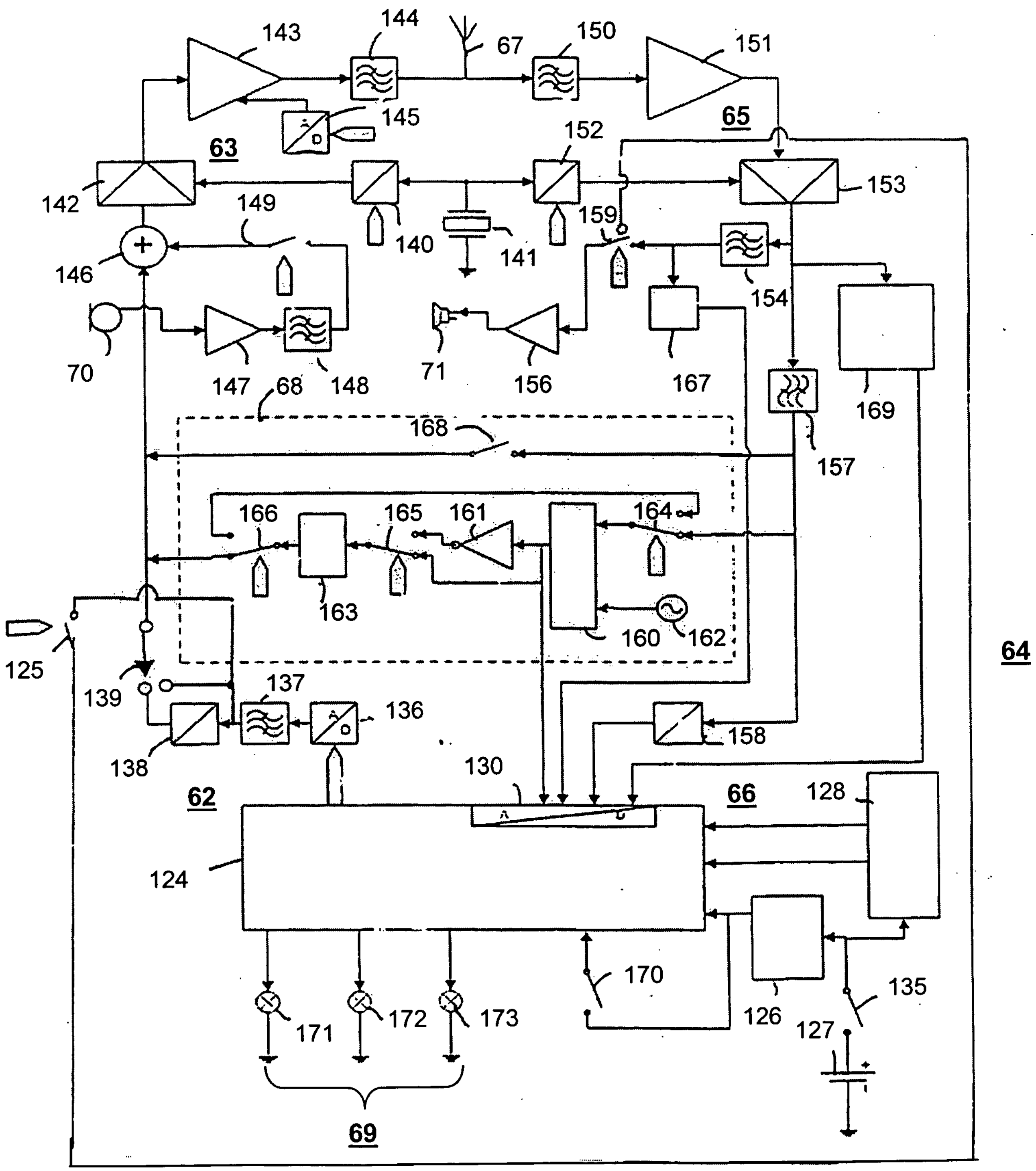

93
94
47
100
101
95
43
45
102
92
90
109
104
103
99
91
96
41
50
97
98
52
106
117
119
48
107
118
44
114
111
116
115
113
110
11
2
89
75
87
86
108
88
42
80
46
78
res
74
gpio
Vcc
76
40
85
51
77
81
49

FIG. 6A



143
144
67
150
151
145
65
63
152
142
153
149
159
140
141
146
154
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71
147
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148
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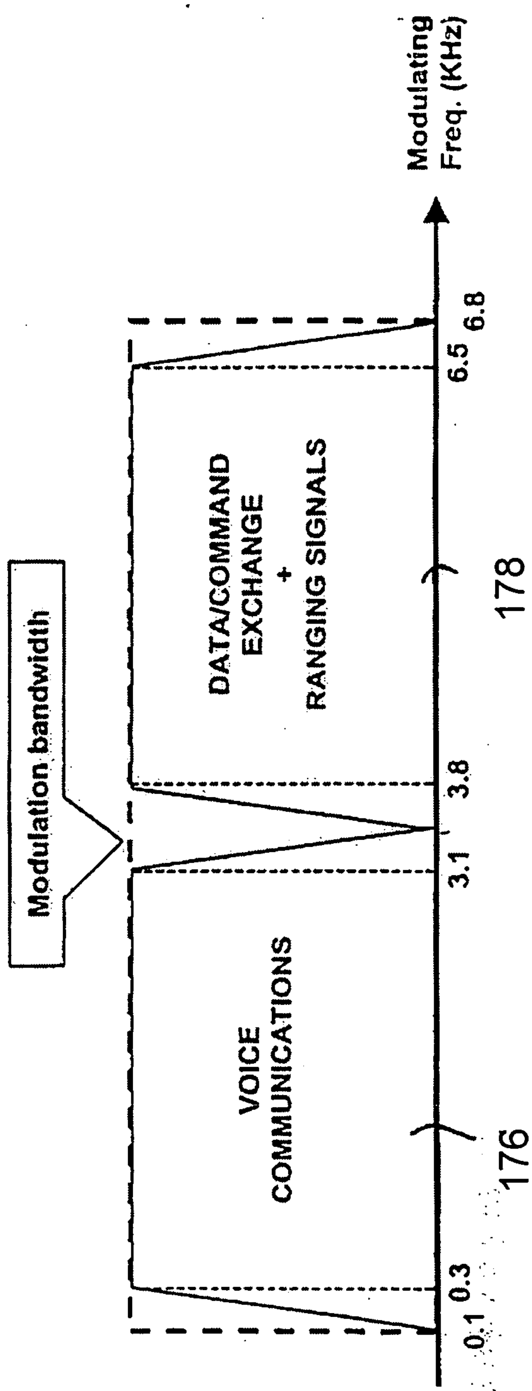
167
169
157
168
164
166
165
161
163
160
162
125
64
139
137
136
138
158
130
62
66
128
124
170
135
126
127
171
172
173
69



Modulating Freq. (KHz)
Modulation bandwidth
VOICE COMMUNICATIONS
DATA/COMMAND EXCHANGE + RANGING SIGNALS
0.1
0.3
3.1
3.8
6.5
6.8
176
178

FIG. 6B

Position Determination Example

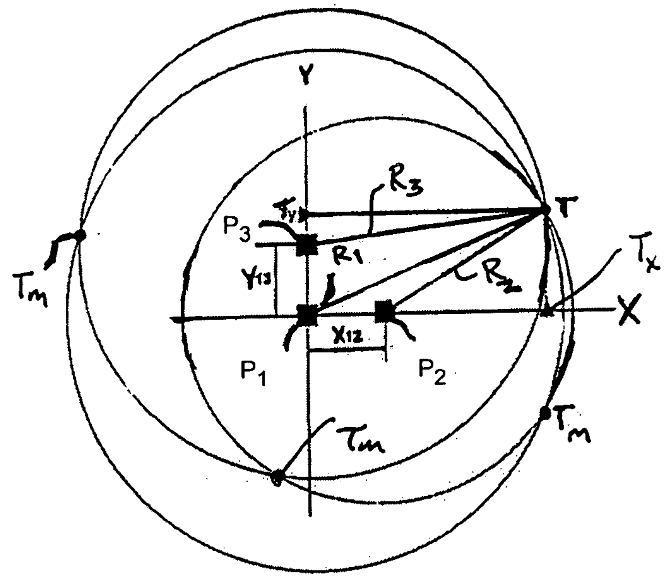


FIG. 7

Position Determination Ambiguity

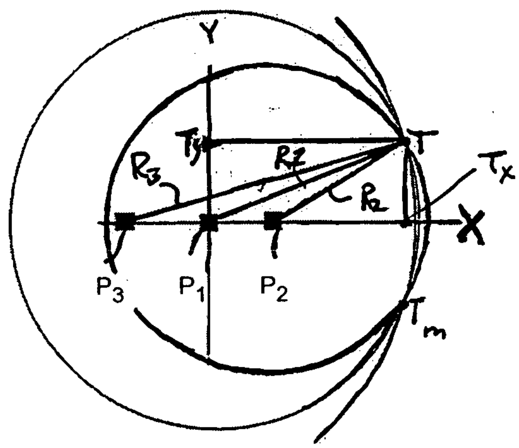
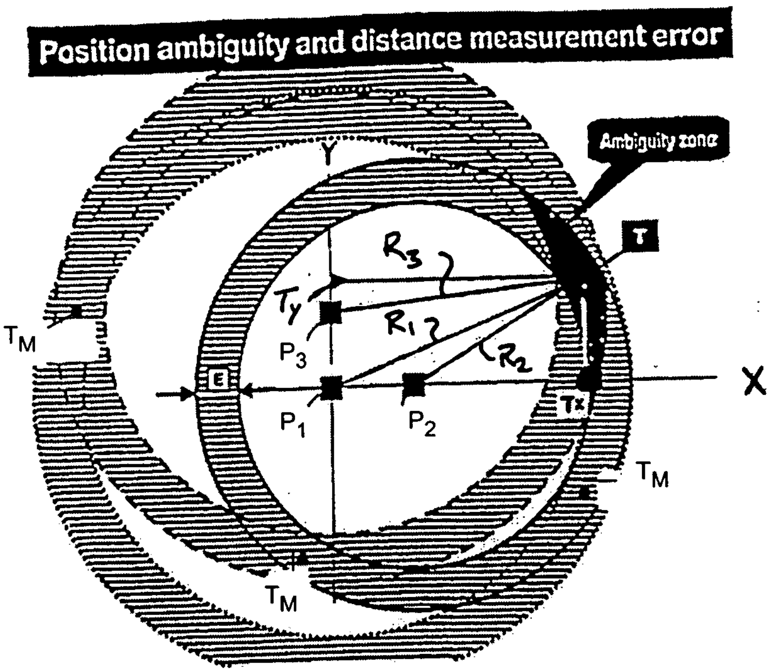
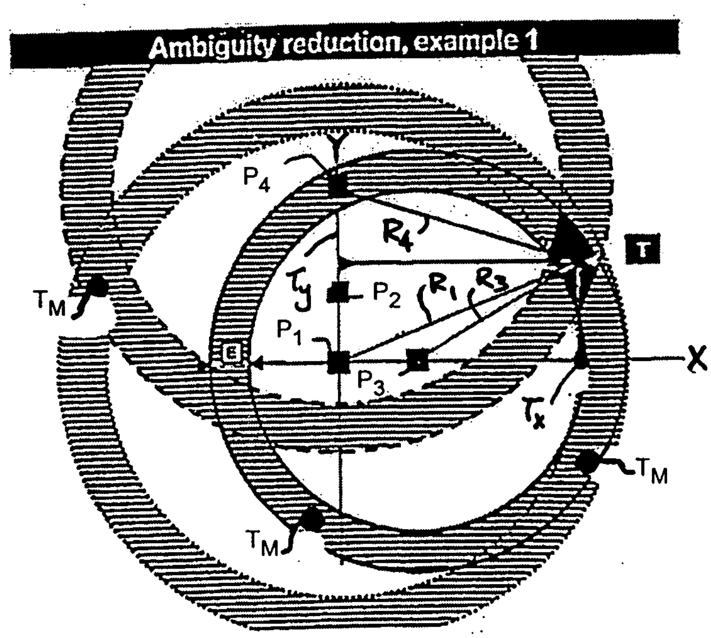


FIG. 8



Position ambiguity and distance measurement error
Ambiguity zone
T
Y
X
R_3
R_1
R_2
T_y
T_x
T_M
T_M
T_M
E
P_1
P_2
P_3

FIG. 9



Ambiguity reduction, example 1
T
Y
X
R_4
R_1
R_3
T_y
T_x
T_M
T_M
T_M
E
P_1
P_2
P_3
P_4

FIG. 10

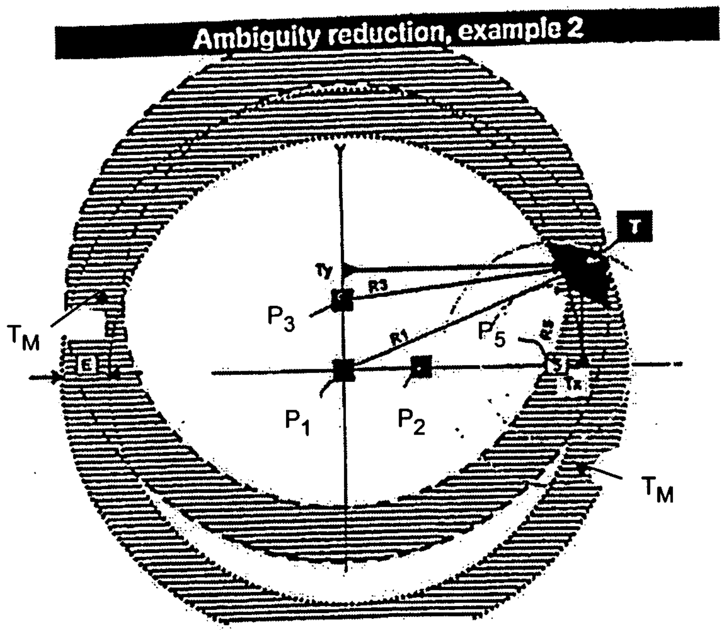
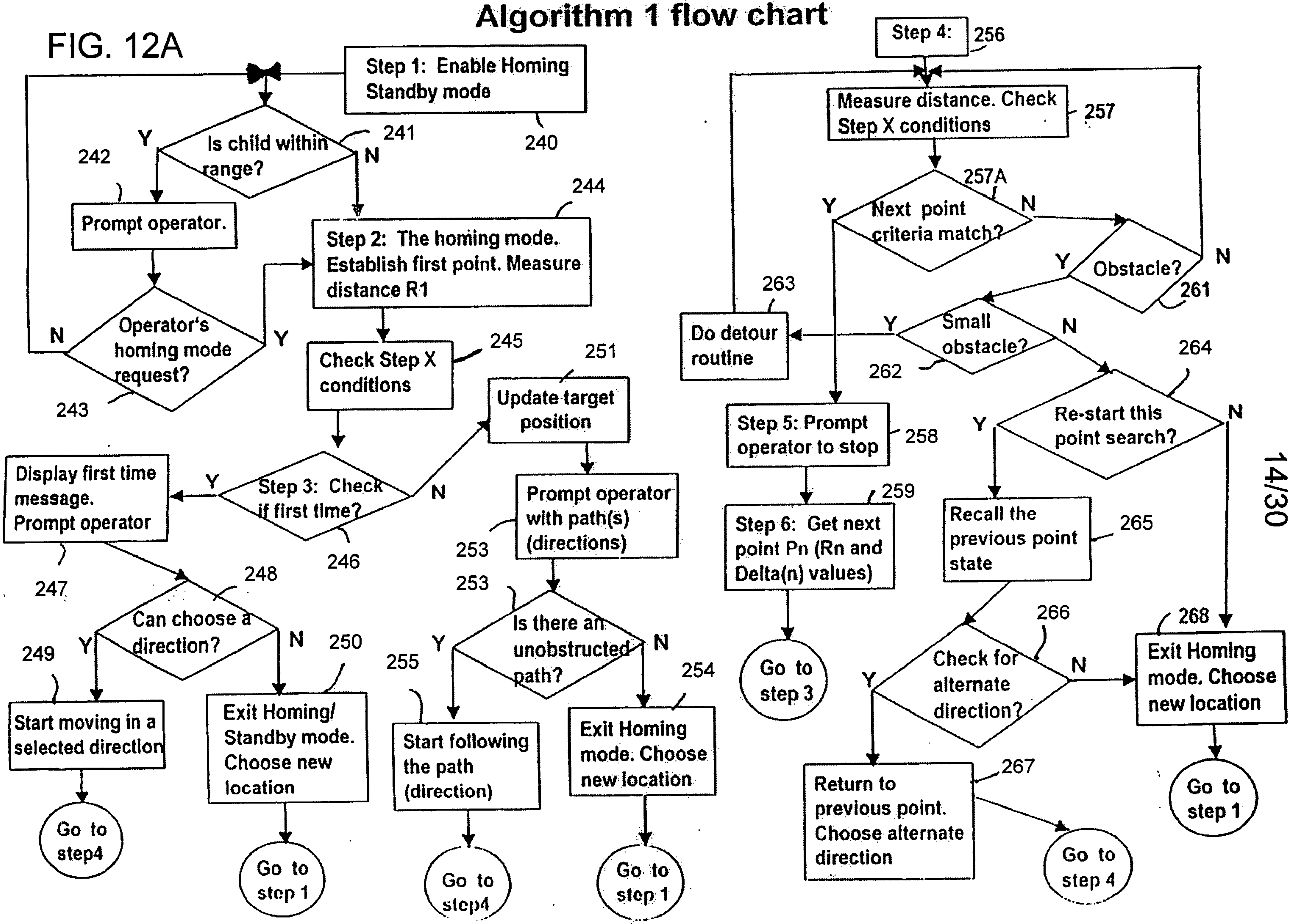


FIG. 11

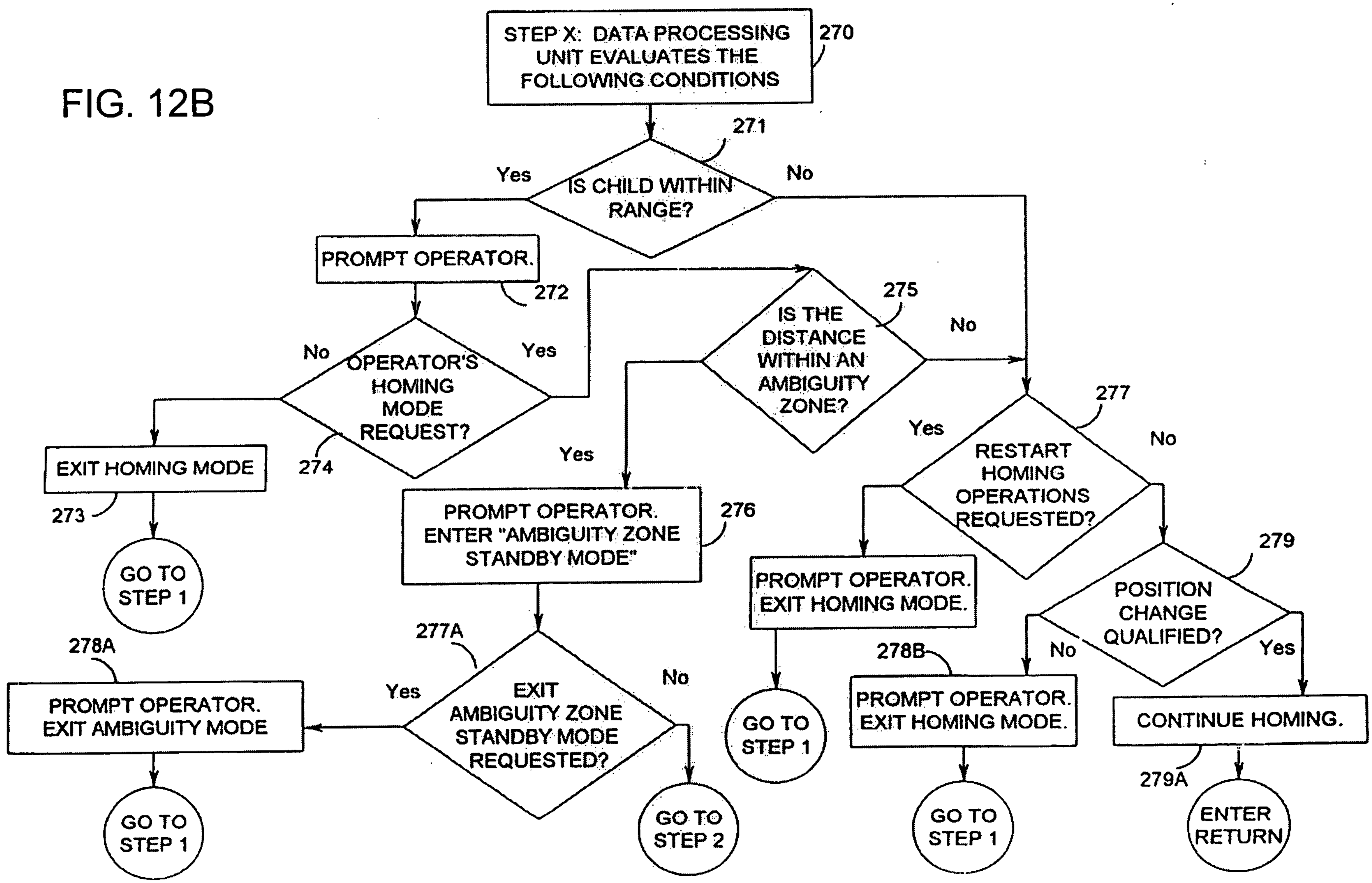
FIG. 12A

Algorithm 1 flow chart



ALGORITHM 1 FLOW CHART, CONTINUED

FIG. 12B



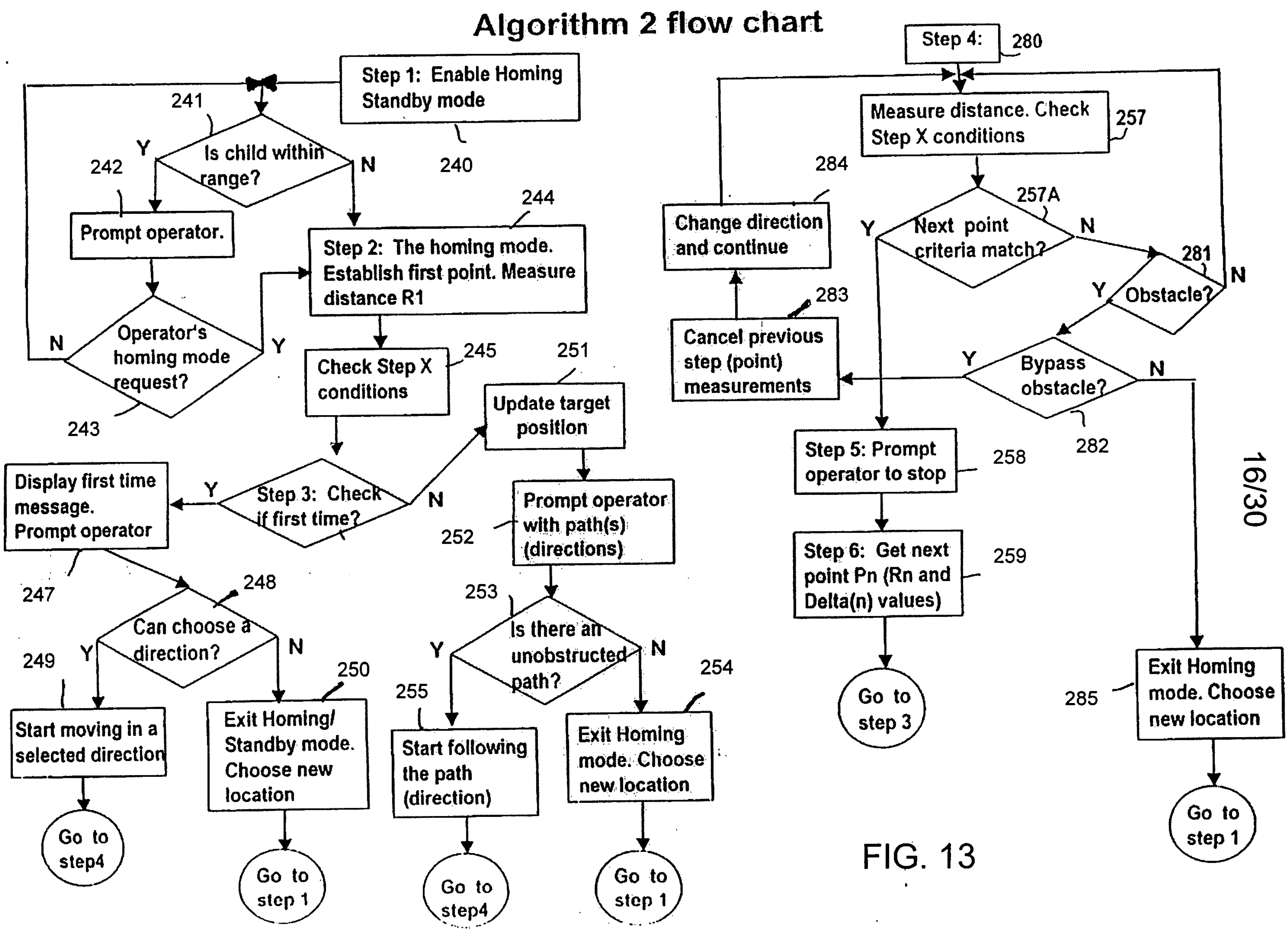

Algorithm 2 flow chart
Step 1: Enable Homing Standby mode
240
241
Is child within range?
Y
N
242
Prompt operator.
243
Operator's homing mode request?
N
Y
244
Step 2: The homing mode. Establish first point. Measure distance R1
245
Check Step X conditions
Step 3: Check if first time?
Y
N
247
Display first time message. Prompt operator
248
Can choose a direction?
Y
N
249
Start moving in a selected direction
Go to step4
250
Exit Homing/ Standby mode. Choose new location
Go to step 1
251
Update target position
252
Prompt operator with path(s) (directions)
253
Is there an unobstructed path?
Y
N
255
Start following the path (direction)
Go to step4
254
Exit Homing mode. Choose new location
Go to step 1
Step 4:
280
Measure distance. Check Step X conditions
257
257A
Next point criteria match?
Y
N
281
Obstacle?
Y
N
282
Bypass obstacle?
Y
N
283
Cancel previous step (point) measurements
284
Change direction and continue
258
Step 5: Prompt operator to stop
259
Step 6: Get next point Pn (Rn and Delta(n) values)
Go to step 3
285
Exit Homing mode. Choose new location
Go to step 1

FIG. 13

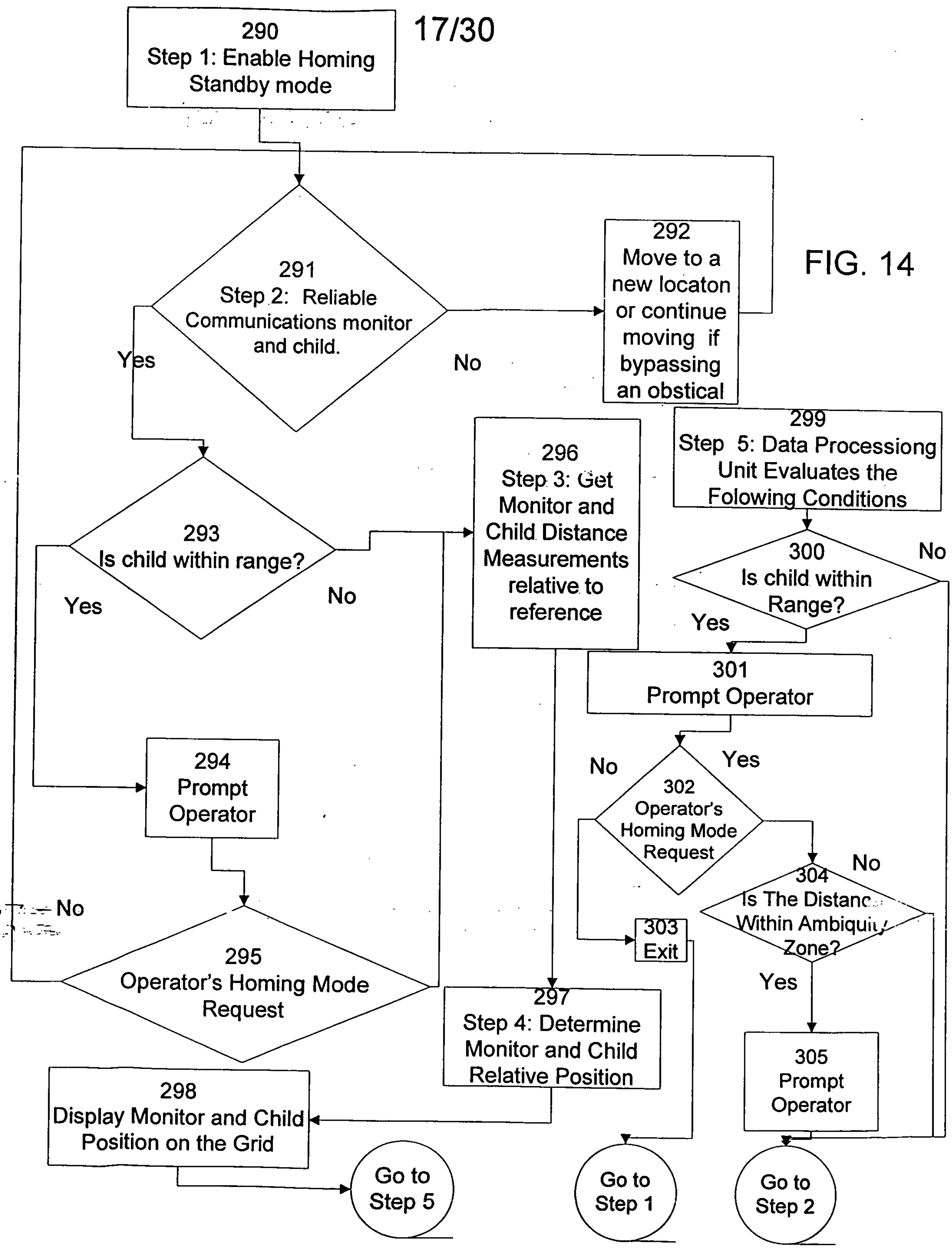

290
Step 1: Enable Homing Standby mode
291
Step 2: Reliable Communications monitor and child.
Yes
No
292
Move to a new locaton or continue moving if bypassing an obstical
293
Is child within range?
Yes
No
294
Prompt Operator
No
295
Operator's Homing Mode Request
296
Step 3: Get Monitor and Child Distance Measurements relative to reference
297
Step 4: Determine Monitor and Child Relative Position
298
Display Monitor and Child Position on the Grid
Go to Step 5
299
Step 5: Data Processiong Unit Evaluates the Folowing Conditions
300
Is child within Range?
No
Yes
301
Prompt Operator
No
Yes
302
Operator's Homing Mode Request
303
Exit
No
304
Is The Distance Within Ambiquity Zone?
Yes
305
Prompt Operator
Go to Step 1
Go to Step 2

FIG. 14

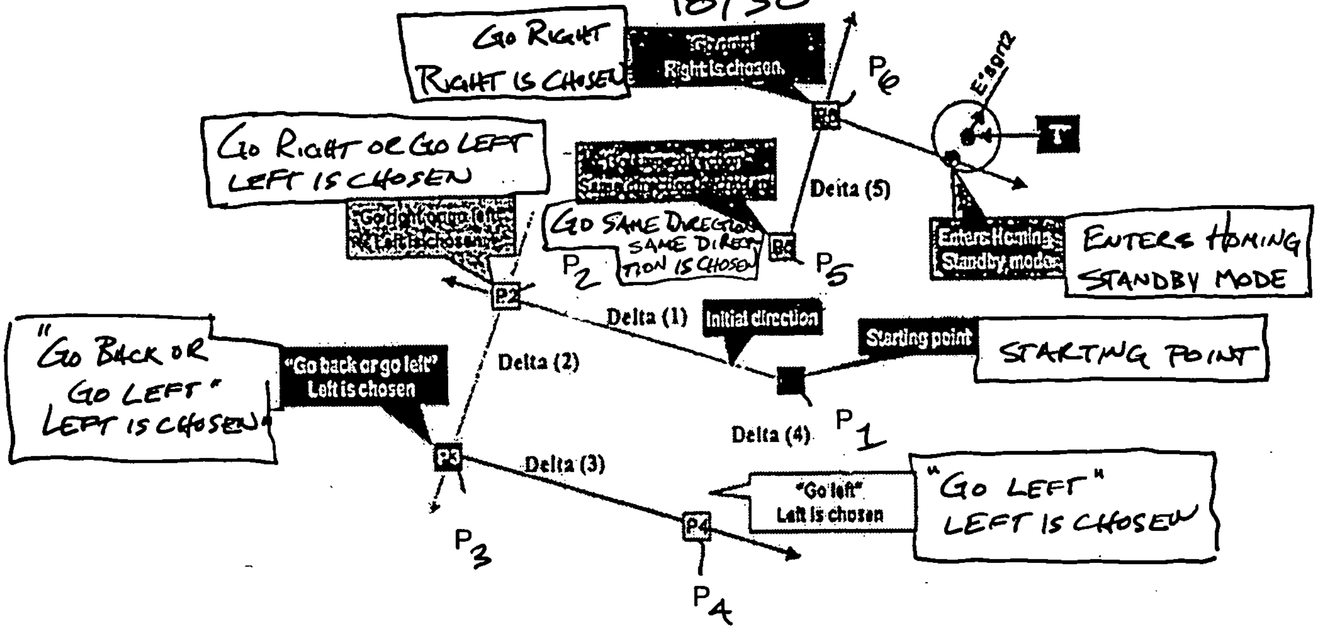

GO RIGHT
RIGHT IS CHOSEN
Right is chosen.
P6
E'sqrt2
T
GO RIGHT OR GO LEFT
LEFT IS CHOSEN
Delta (5)
GO SAME DIRECTION
SAME DIRECTION IS CHOSEN
P2
P5
Enters Homing Standby mode
ENTERS HOMING STANDBY MODE
P2
Delta (1)
Initial direction
Starting point
STARTING POINT
"GO BACK OR GO LEFT"
LEFT IS CHOSEN
"Go back or go left"
Left is chosen
Delta (2)
Delta (4)
P1
P3
Delta (3)
"Go left"
Left is chosen
"GO LEFT"
LEFT IS CHOSEN
P4
P3
P4

FIG. 15

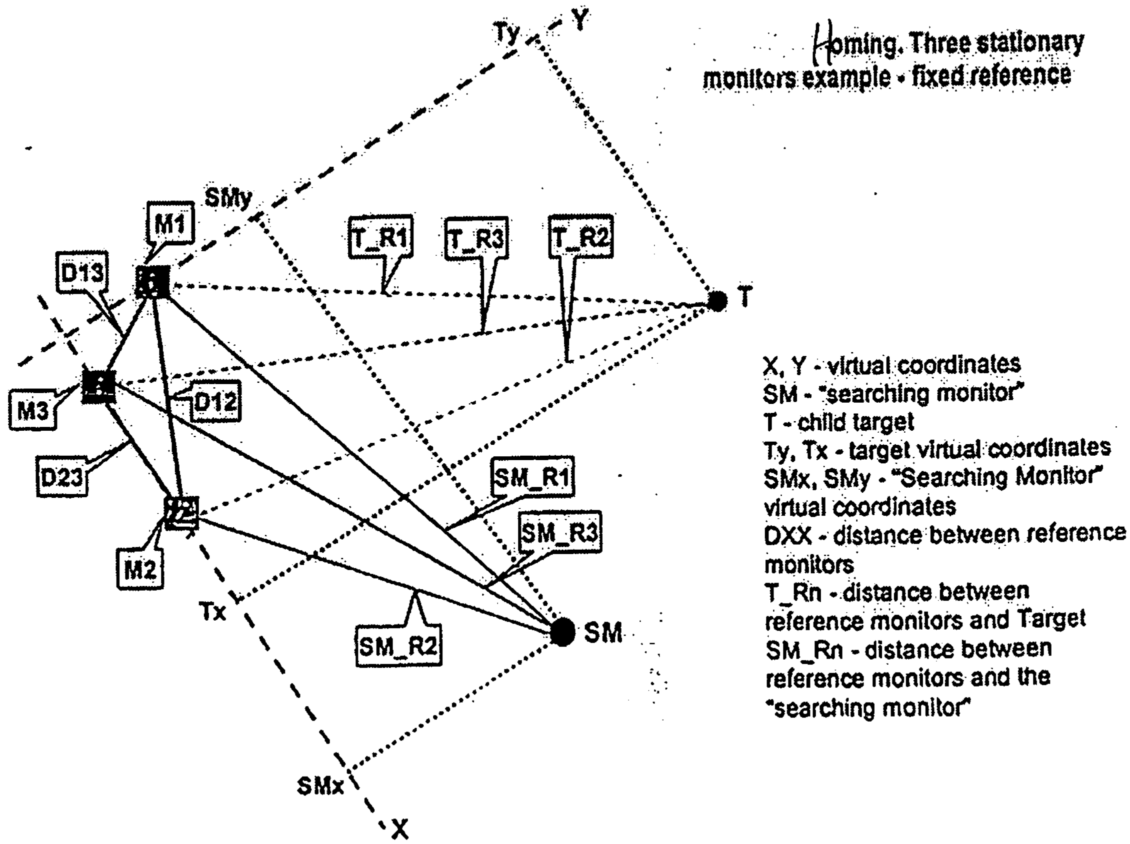

Homing. Three stationary monitors example - fixed reference
Ty
Y
SMy
M1
T_R1
T_R3
T_R2
D13
T
M3
D12
D23
SM_R1
SM_R3
M2
Tx
SM_R2
SM
SMx
X
X, Y - virtual coordinates
SM - "searching monitor"
T - child target
Ty, Tx - target virtual coordinates
SMx, SMy - "Searching Monitor" virtual coordinates
DXX - distance between reference monitors
T_Rn - distance between reference monitors and Target
SM_Rn - distance between reference monitors and the "searching monitor"

FIG. 16

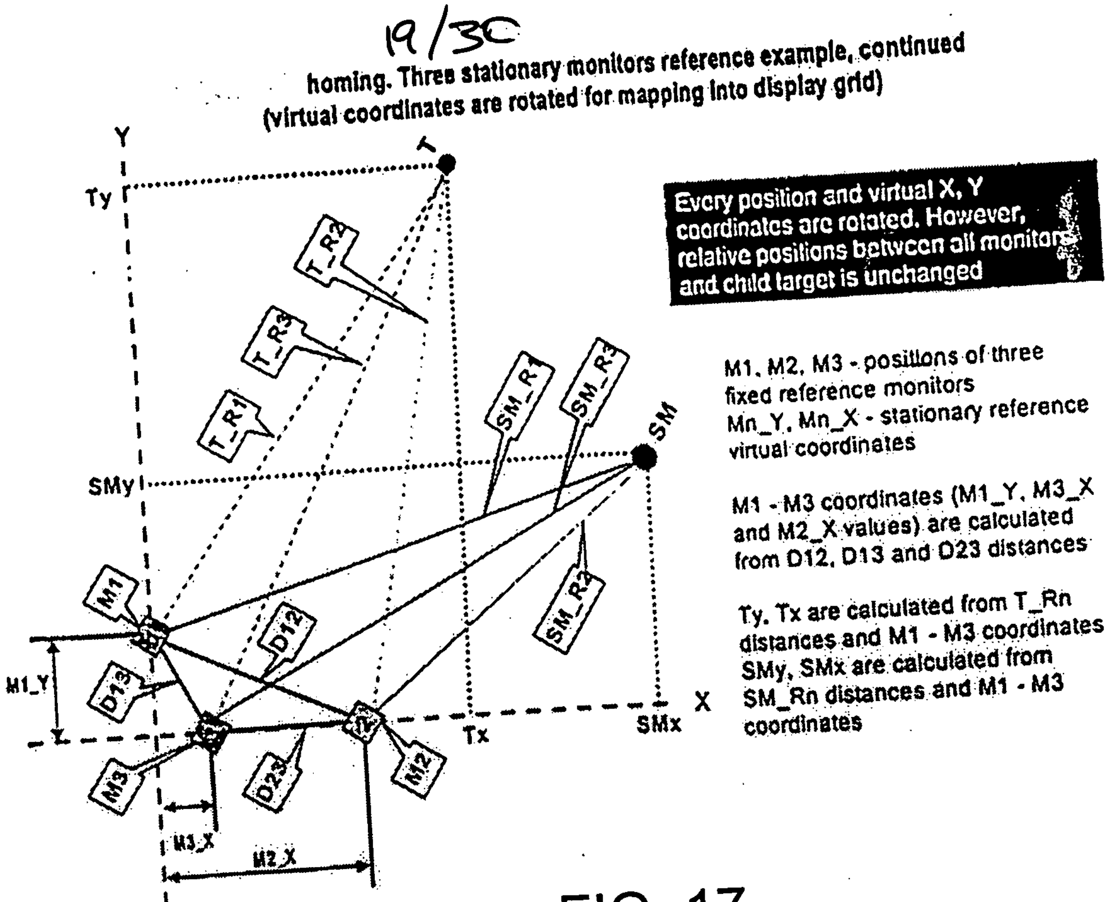

homing. Three stationary monitors reference example, continued
(virtual coordinates are rotated for mapping into display grid)
Y
Ty
T
T_R2
T_R3
T_R1
SM_R1
SM_R3
SM
SMy
SM_R2
M1
D12
D13
M1_Y
M3
D23
M2
M3_X
M2_X
Tx
SMx
X
Every position and virtual X, Y coordinates are rotated. However, relative positions between all monitors and child target is unchanged
M1, M2, M3 - positions of three fixed reference monitors
Mn_Y, Mn_X - stationary reference virtual coordinates
M1 - M3 coordinates (M1_Y, M3_X and M2_X values) are calculated from D12, D13 and D23 distances
Ty, Tx are calculated from T_Rn distances and M1 - M3 coordinates
SMy, SMx are calculated from SM_Rn distances and M1 - M3 coordinates

FIG. 17

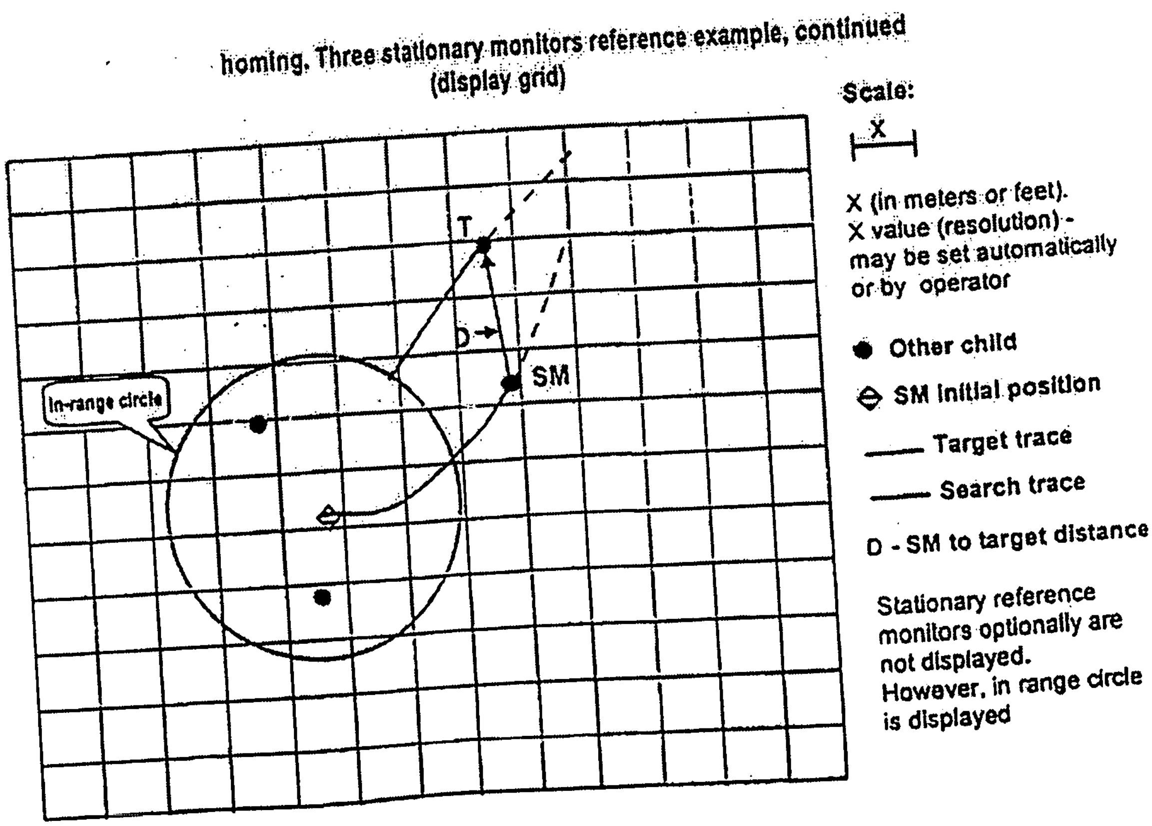

homing. Three stationary monitors reference example, continued
(display grid)
Scale:
X
X (in meters or feet).
X value (resolution) - may be set automatically or by operator
Other child
SM initial position
Target trace
Search trace
D - SM to target distance
Stationary reference monitors optionally are not displayed. However, in range circle is displayed
T
D
SM
In-range circle

FIG. 18

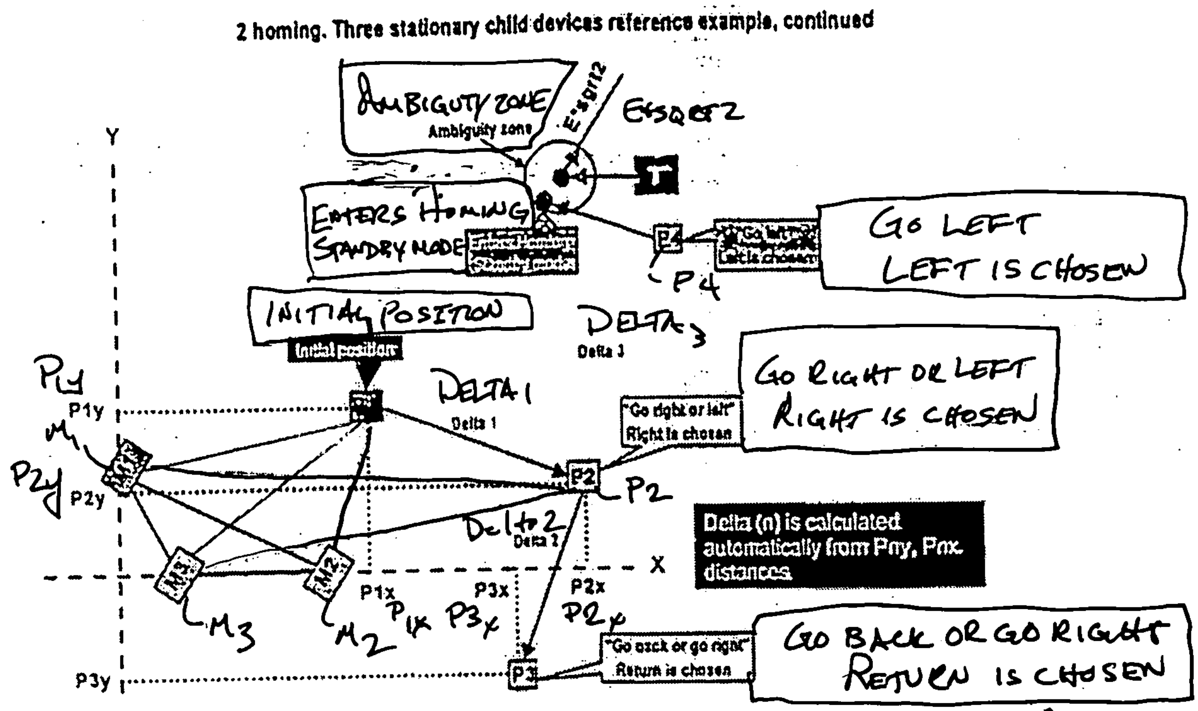

2 homing. Three stationary child devices reference example, continued
AMBIGUTY ZONE
Ambiguity zone
E*sqrt2
ESSQRT2
T
ENTERS HOMING STANDBY MODE
Enters Homing Standby mode
"Go left" Left is chosen
GO LEFT LEFT IS CHOSEN
P4
INITIAL POSITION
Initial position
DELTA 3
Delta 3
DELTA 1
Delta 1
"Go right or left" Right is chosen
GO RIGHT OR LEFT RIGHT IS CHOSEN
P1y
P2y
P3y
M1
M2
M3
P2
Delta 2
Delta (n) is calculated automatically from Pny, Pnx distances
X
Y
P1x
P3x
P2x
"Go back or go right" Return is chosen
GO BACK OR GO RIGHT RETURN IS CHOSEN

FIG. 21

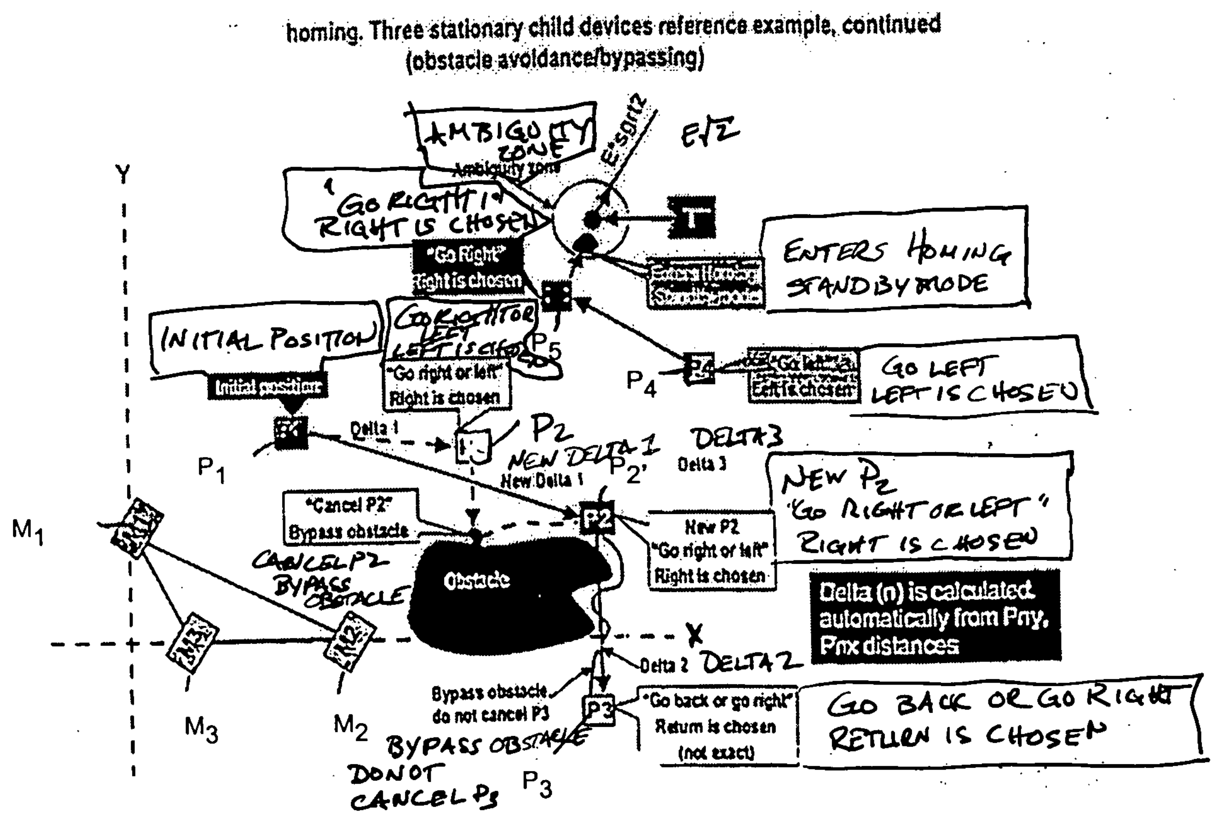
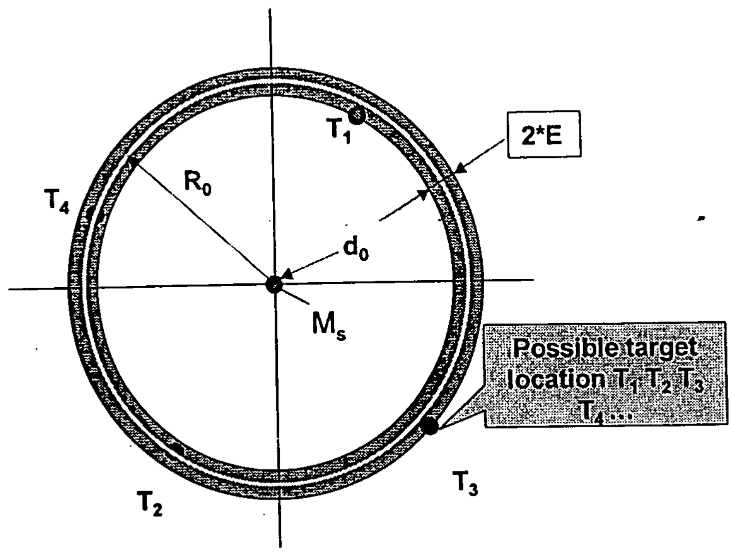
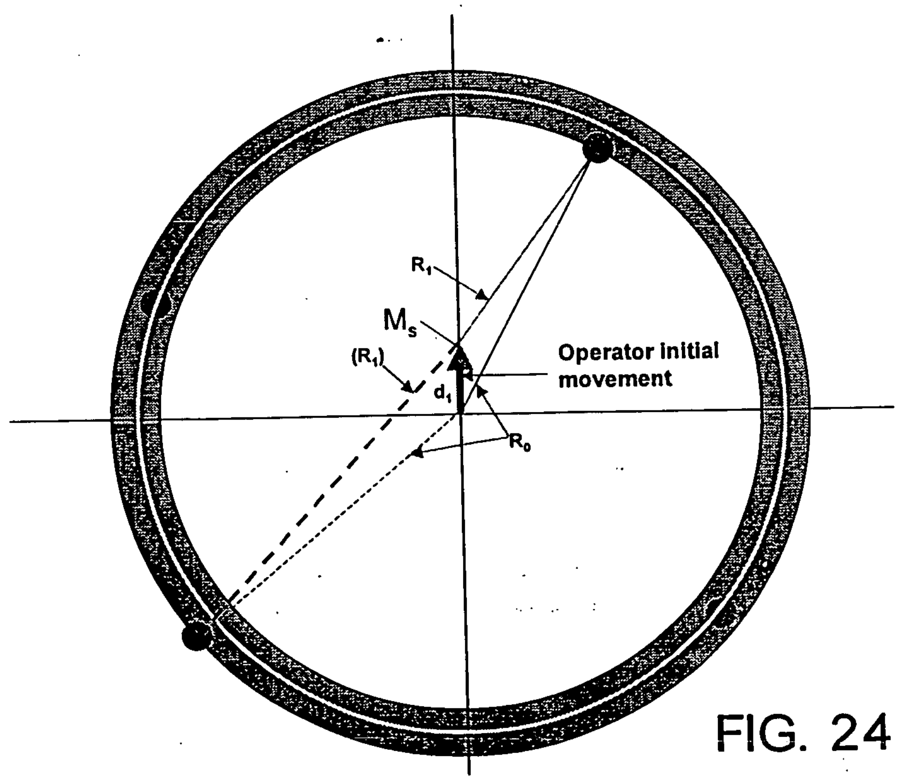

homing. Three stationary child devices reference example, continued
(obstacle avoidance/bypassing)
AMBIGUITY ZONE
Ambiguity zone
E*sqrt2
E√2
'GO RIGHT' RIGHT IS CHOSEN
"Go Right" Right is chosen
T
ENTERS HOMING STANDBY MODE
Enters Homing Standby mode
INITIAL POSITION
Initial position
GO RIGHT OR LEFT LEFT IS CHOSEN
"Go right or left" Right is chosen
P5
P4
"Go left" Left is chosen
GO LEFT LEFT IS CHOSEN
Delta 1
P2
NEW DELTA 1
New Delta 1
P2'
DELTA3
Delta 3
P1
"Cancel P2" Bypass obstacle
CANCEL P2 BYPASS OBSTACLE
Obstacle
NEW P2 "GO RIGHT OR LEFT" RIGHT IS CHOSEN
New P2 "Go right or left" Right is chosen
Delta (n) is calculated automatically from Pny, Pnx distances
M1
M2
M3
X
Y
Delta 2
DELTA 2
Bypass obstacle do not cancel P3
BYPASS OBSTACLE DO NOT CANCEL P3
P3
"Go back or go right" Return is chosen (not exact)
GO BACK OR GO RIGHT RETURN IS CHOSEN

FIG. 22



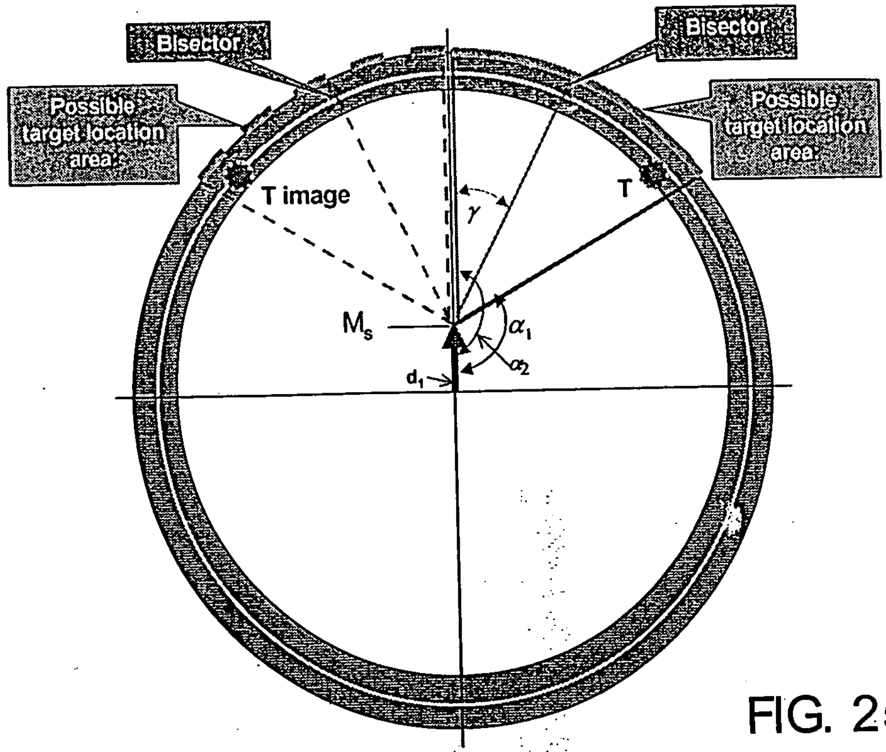
T1
2*E
R0
T4
d0
Ms
Possible target location T1 T2 T3 T4...
T3
T2

FIG. 23



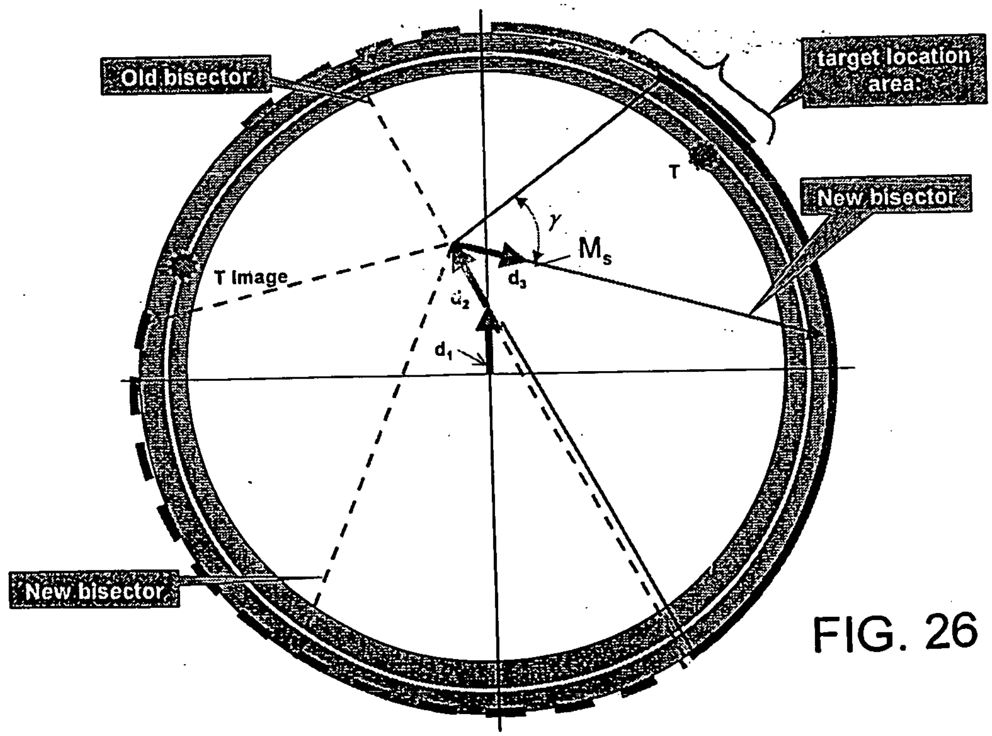
R1
Ms
(R1)
d1
Operator initial movement
R0

FIG. 24



Bisector
Bisector
Possible target location area
Possible target location area
T image
T
γ
M_s
α_1
α_2
d_1

FIG. 25



Old bisector
target location area
T
New bisector
γ
M_s
T image
d_3
d_2
d_1
New bisector

FIG. 26

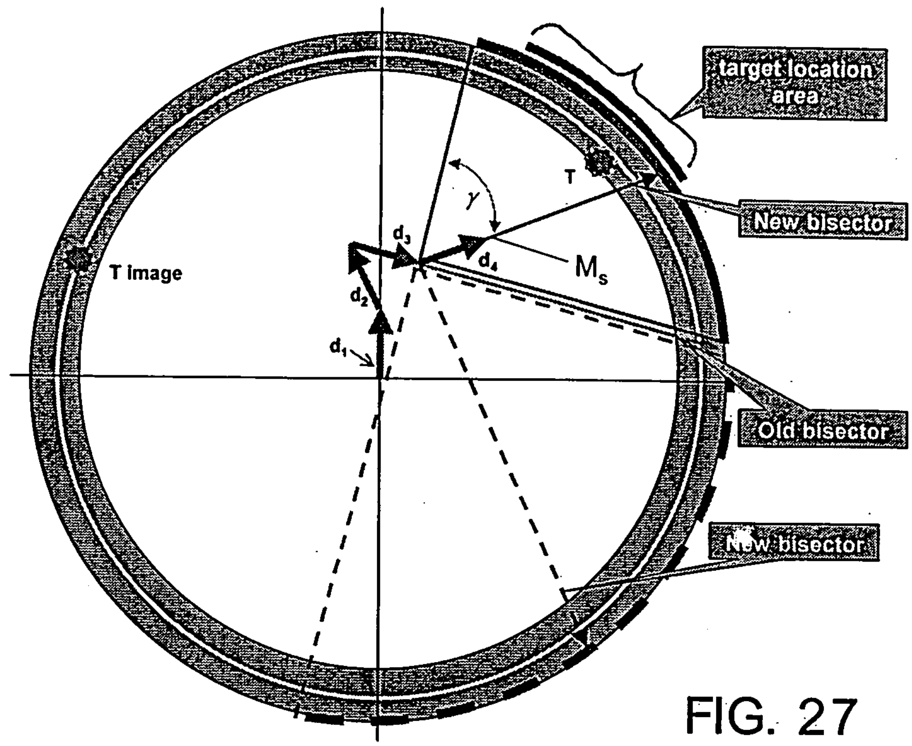

target location area
New bisector
T
γ
d3
d4
Ms
T image
d2
d1
Old bisector
New bisector

FIG. 27

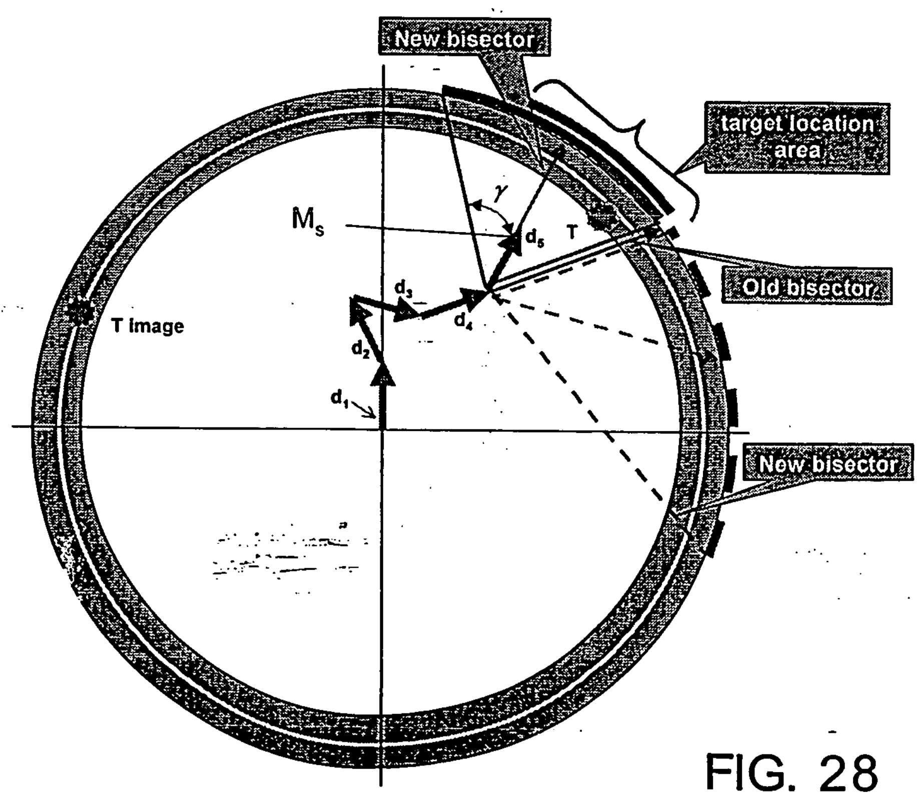

New bisector
target location area
γ
Ms
d5
T
d3
Old bisector
T image
d4
d2
d1
New bisector

FIG. 28

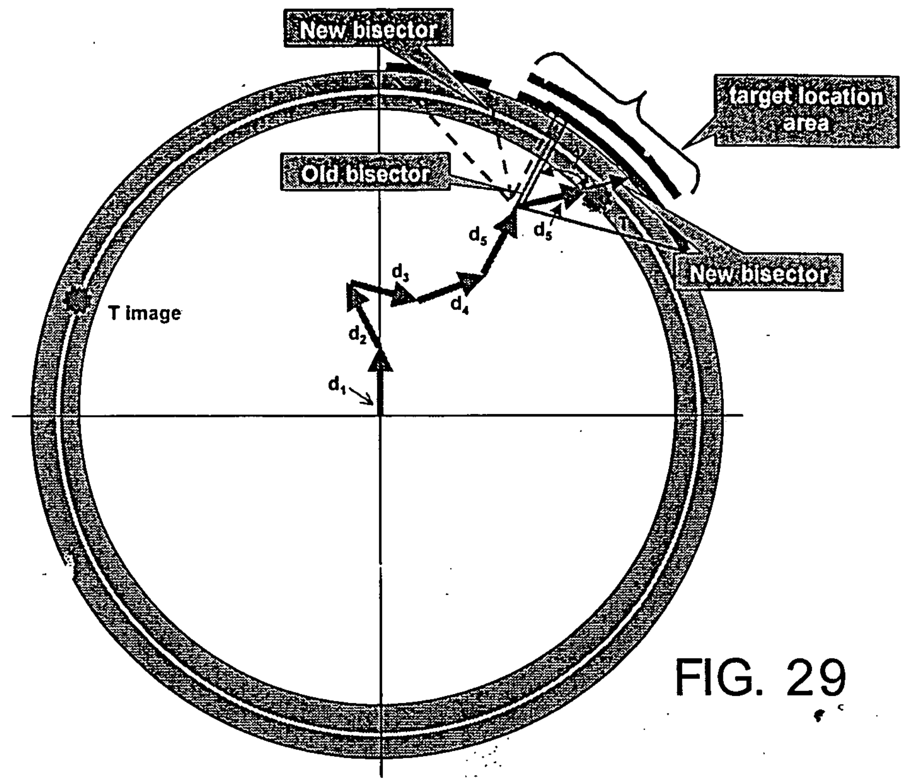

New bisector
target location area
Old bisector
d_5
d_5'
New bisector
d_3
d_4
T image
d_2
d_1

FIG. 29

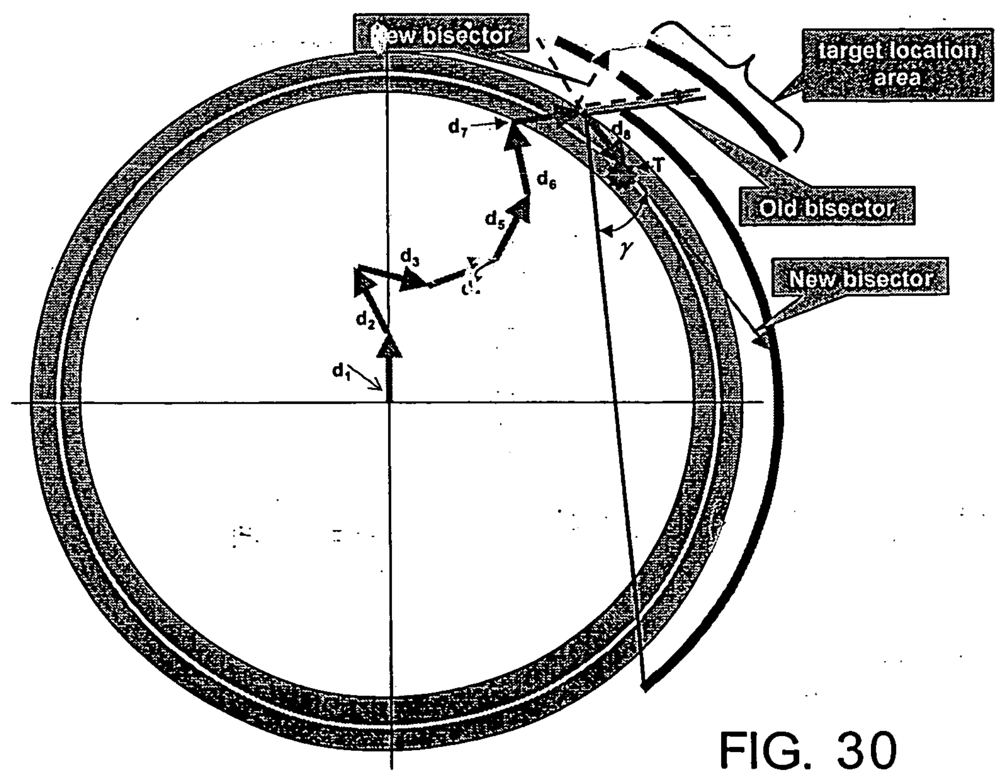

New bisector
target location area
d_7
d_8
T
d_6
Old bisector
d_5
γ
d_3
New bisector
d_2
d_1

FIG. 30

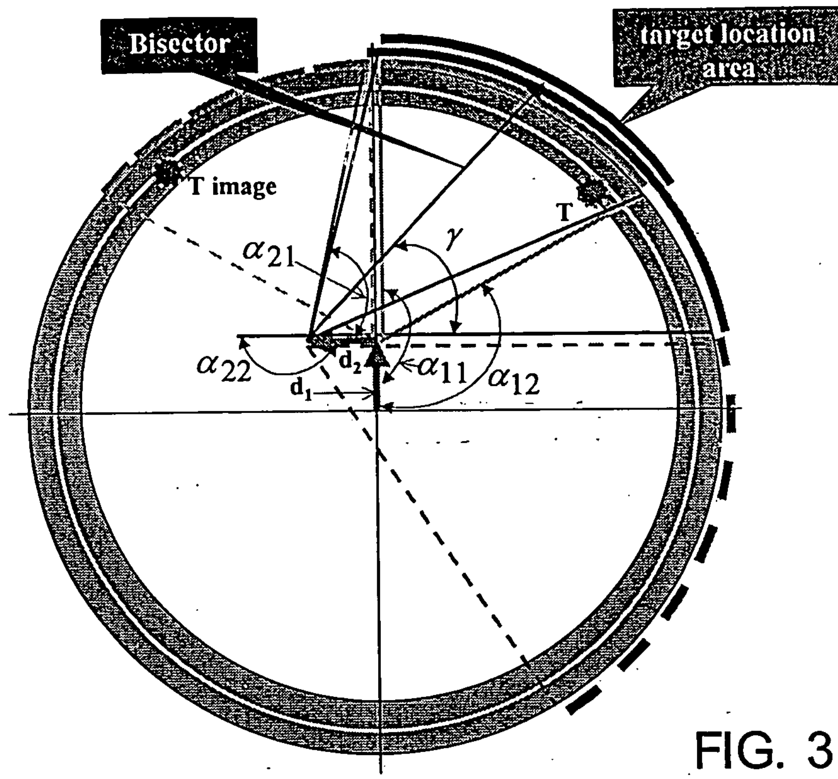

Bisector
target location area
T image
T
α_{21}
γ
α_{22}
d_2
d_1
α_{11}
α_{12}

FIG. 31

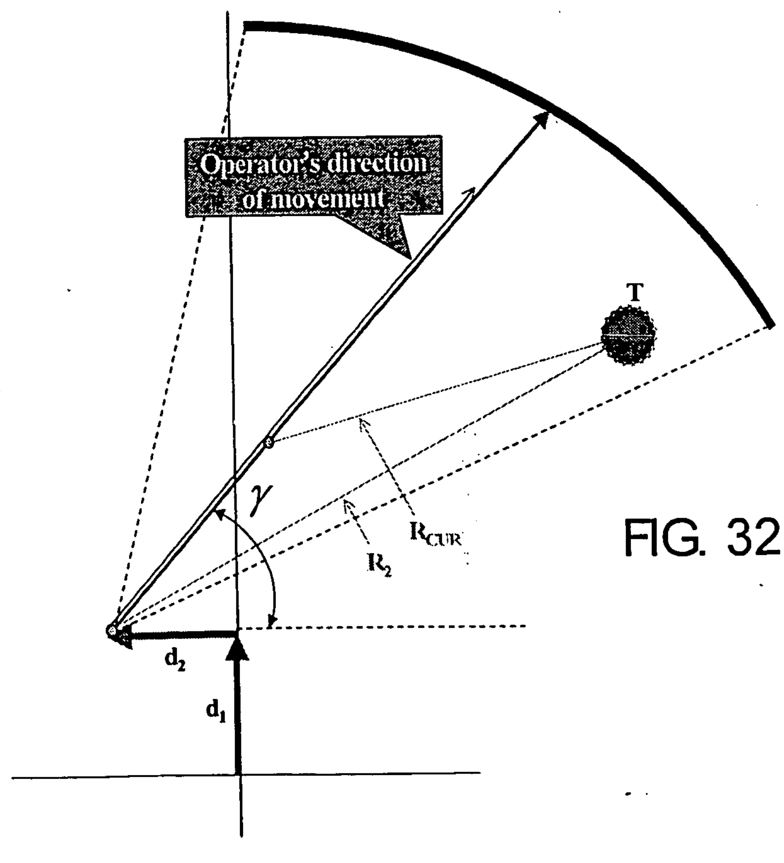

Operator's direction of movement
T
γ
R_{CUR}
R_2
d_2
d_1

FIG. 32

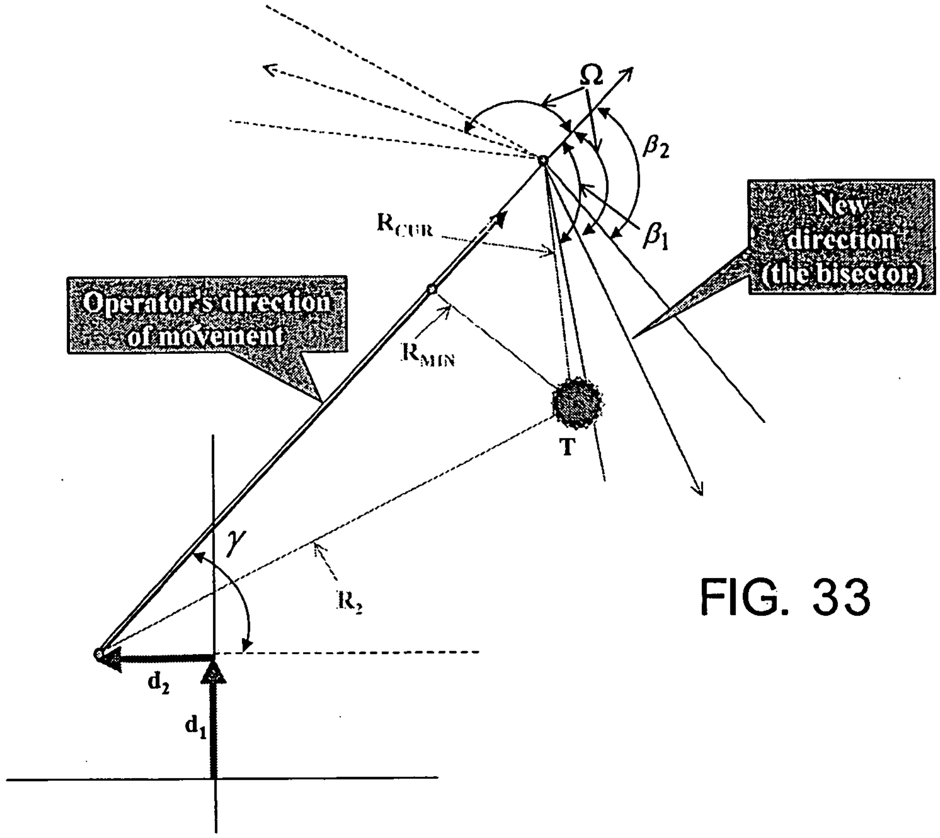

Ω
β_2
β_1
R_{CUR}
New direction (the bisector)
Operator's direction of movement
R_{MIN}
T
γ
R_2
d_2
d_1

FIG. 33

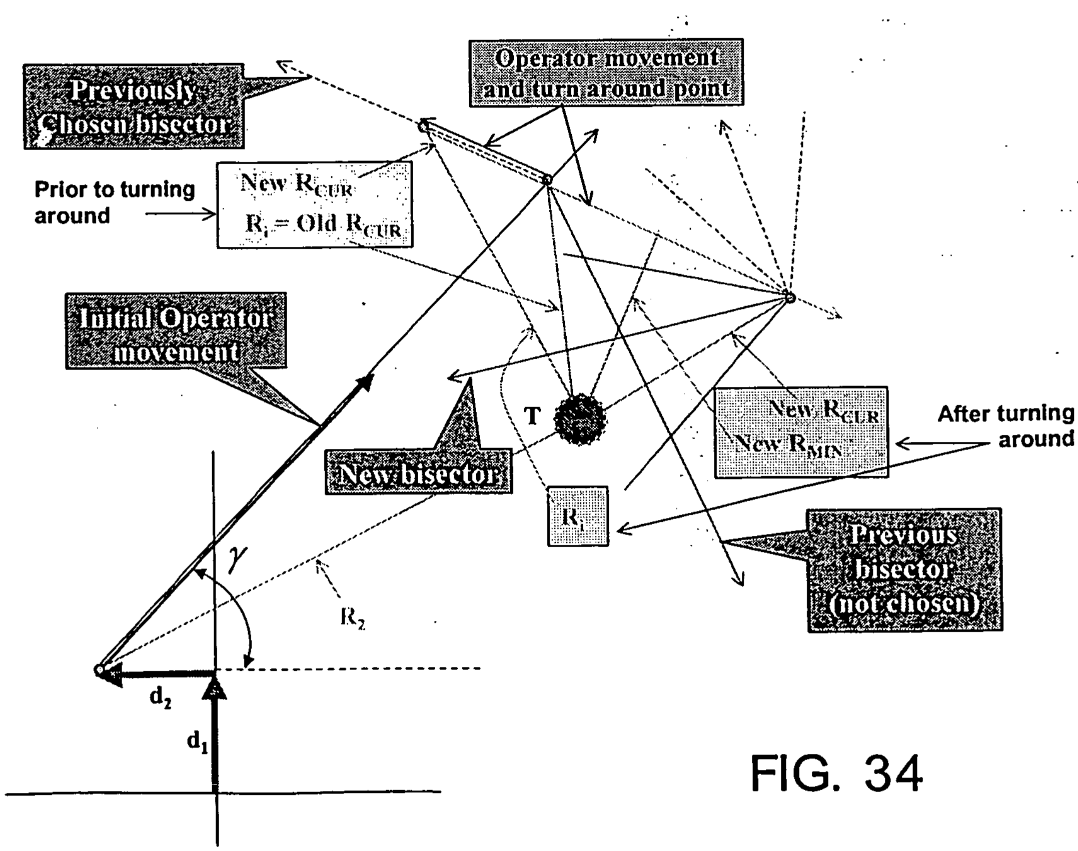
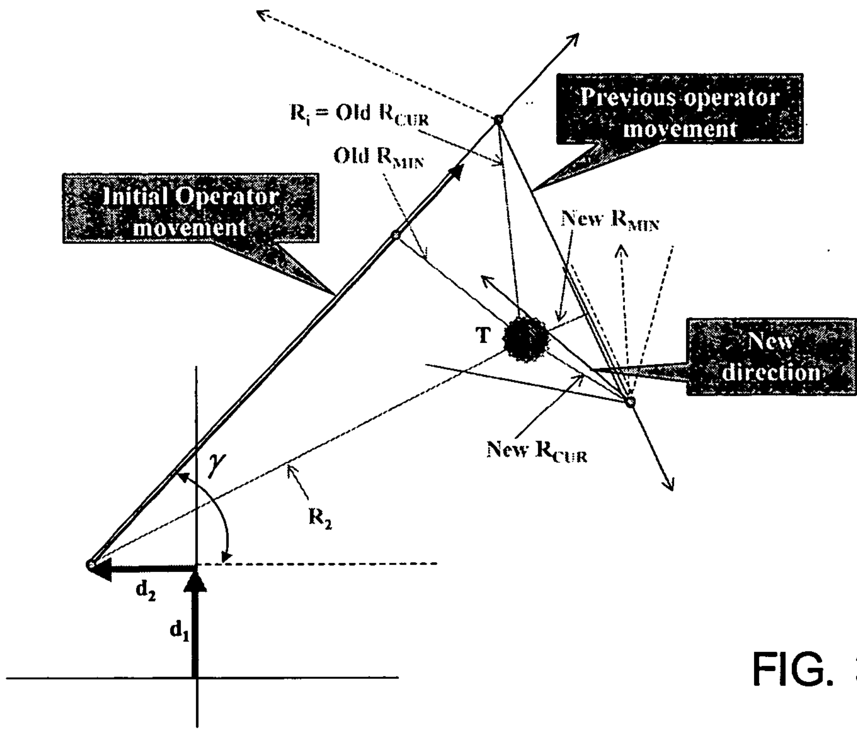
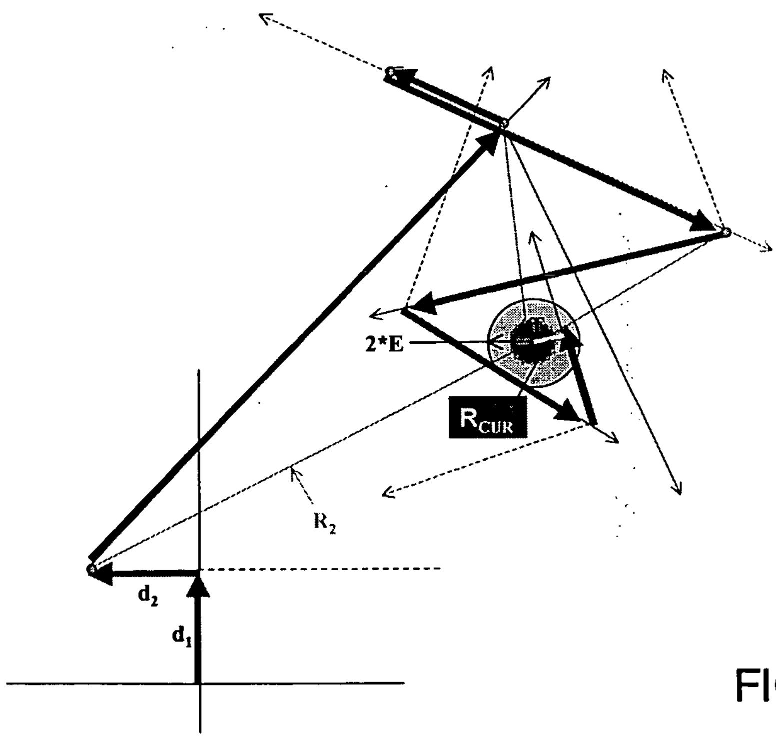

Operator movement and turn around point
Previously Chosen bisector
Prior to turning around
New R_{CUR}
R_i = Old R_{CUR}
Initial Operator movement
T
New bisector
New R_{CUR}
New R_{MIN}
After turning around
R_i
Previous bisector (not chosen)
γ
R_2
d_2
d_1

FIG. 34



R_i = Old R_CUR
Previous operator movement
Old R_MIN
Initial Operator movement
New R_MIN
T
New direction
New R_CUR
γ
R_2
d_2
d_1

FIG. 35



2*E
R_CUR
R_2
d_2
d_1

FIG. 36

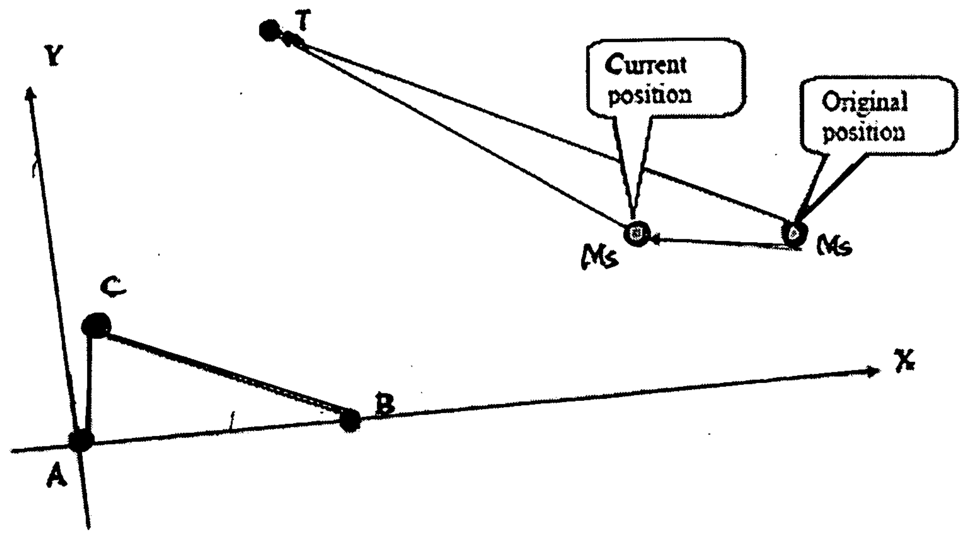


FIG. 37A

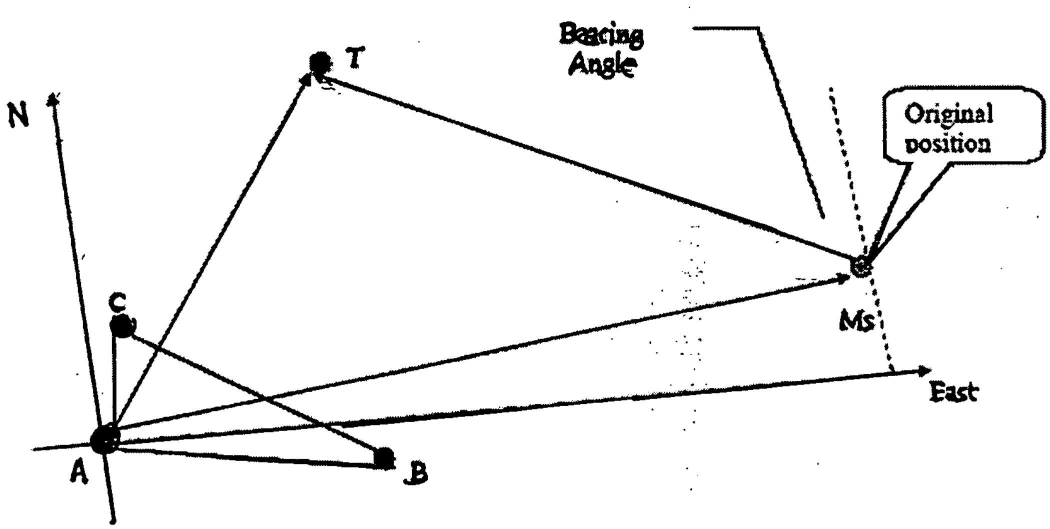


FIG. 37B